School of Graduate Studies

Jimma Institute of Technology

Faculty of Civil and Environmental Engineering

Construction Engineering and Management Chair

REPLACEMENT OF SCORIA WITH WASTAGE OF AMBO SANDSTONE FOR THE PRODUCTION OF HOLLOW CONCRETE BLOCKS

A Thesis submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Construction Engineering and Management

By: Ashenafi Hirpha

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Advisor: Dr.Ing. Fekadu Fufa

Co-advisor: Mr. Sintayehu Assefa (MSc)

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By:

Ashenafi Hirpha Wantolu

Approved by board of examiners:

1. Dr. -Ing. Fekadu Fufa	________________	/ /
Main Advisor	Signature	Date
2. Mr. Sintayehu Assefa (MSc.)	________________	/ /
Co-advisor	Signature	Date
3. ________________	________________	/ /
External Examiner	Signature	Date
4. ________________	________________	/ /
Internal Examiner	Signature	Date
5. ________________	________________	/ /
Chairperson	Signature	Date

DECLARATION

I,Ashenafi Hirpha, the undersigned declare that the MSc thesis entitled **"Replacement of scoria with wastage of Ambo sandstone for the production of hollow concrete blocks"** which is original work of my own, has not been presented to any other university and that all sources of materials used in this thesis have been duly acknowledged.

Name: Ashenafi Hirpha Wantolu _______________ _______________

Signature Date

Place: Jimma University Institute of Technology

Faculty of Civil and Environmental Engineering (Construction Engineering and Management Stream)

Date: October, 2017

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

Main Advisor:

Dr.-Ing. Fikadu Fufa ___________________ ___________________

Signature Date

Co-Advisor:

Mr. Sintayehu Assefa (MSc) ____________________ ___________________

Signature Date

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ABSTRACT

One of the most important ingredients of hollow concrete block (HCB) is aggregate that differ depending on their classification. The most common aggregate used for HCB are pumice and scoria. As many researchers conducted the concrete produced from both aggregate are light weight and also the aggregate in hollow concrete blocks are partially or totally replaced with different types of materials and wastage of some product to reduce the environmental pollution.

The main objective of this study was to investigate the relevance of hollow concrete block produced as replacement of scoria with wastage of Ambo sandstone. Specifically it focused in determining the physical properties of wastage of Ambo sandstone aggregates and scoria, determine compressive strength of hollow concrete blocks produced at each replacement and to compare the production cost. In addition workability, unit weight and water absorption of hollow concrete were conducted.

This experimental study was conducted by preparing of hollow concrete blocks test sample and 108 HCB sample was produced. The test sample of hollow concrete blocks was produced by using mix proportion 1:4:2 of cement, scoria and 01 crushed aggregate. Out of the four parts of scoria aggregate, scoria was replaced with 20, 40, 60, 80 and 100% amount of wastage of Ambo sandstone by volume.

According to this study, the hollow concrete block with 100% scoria achieved 3.85Mpa mean compressive strength and the hollow concrete block with 100% wastage of Ambo sandstone achieved 6.83Mpa mean compressive strength. The production cost of all hollow concrete blocks with wastage of Ambo sandstone was lower than hollow concrete block without wastage of Ambo sandstone. According to the water absorption comparison made the hollow concrete block with wastage of Ambo sandstone was found lesser absorptive and heavier than without wastage of Ambo sandstone.

Hollow concrete block with wastage of Ambo sandstone in this study has achieved better cost reduction in production cost, smaller increase in weight, reduction in water absorption and high increase in compressive strength than hollow concrete blocks without wastage of Ambo sandstone. The study further recommended to the construction industry in Ambo and around Ambo town to use wastage of Ambo sandstone for production hollow concrete blocks instead of other aggregate.

Keywords: *Ambo sandstone, compressive strengths, hollow concrete block, production cost and scoria.*

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ABREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
A/C	Aggregate Cement Ratio
ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BS	British Standard
BSG	Bulk specific gravity
EBCS	Ethiopian Building Code Standard
ES	Ethiopian Standard
ETB	Ethiopian Birr
GAR	Grain Area Ration
GTZ	Deutsche Gesellschaft fuer Technische Zusammenarbeit
HCB	Hollow Concrete Block
OPC	Ordinary Portland cement
PC	Pozzolan Cement
PPC	Pozzolan Portland cement
SA	Scoria Aggregate
SC	Scoria Concrete
SRCCD	Swiss Resource Center and Consultancy for Development
W/C	Water Cement Ratio

CHAPTER ONE

INTRODUCTION

1.1. Background

To get shelter human being uses different types of construction materials those are proper with their environment and living standard. The construction material used in developed country is different from developing one. According to Thorat (2015), the human being started using construction material by the use of easily available material like mud in construction walls and burnt clay brick masonry as structural part of shelter.

Masonry was defined as the assemblage of building units joined with the help of cementations material or any accepted joining material to perform required function (Madan, 2015).Wall as one of non-structural parts in a building is usually considered to be light material based. Concrete block and clay block are still chosen to be one of the most selected materials so that the strength can be fulfilled to support the loading even though the self-weight of the wall cannot be considered light at last (Musalamah, 2016).

Concrete is a construction material which consists of the mixture of fine aggregates, coarse aggregates, cement which is proportionally mixed with certain percentage of water (Thorat, 2015).Now days hollow concrete blocks is becoming very popular and being widely used in construction of residential buildings, factories and multi-storied buildings. Hollow concrete is an important addition to the types of masonry units available to the builders and its use for masonry is constantly increasing. Concrete blocks are produced in a large variety of shapes and sizes. Solid, cellular or hollow, dense or lightweight, air-cured or steam-cured, load bearing or non-load bearing, and can be produced manually or with the help of machines (SRCCD, 2008). Hollow blocks are the most common types of concrete blocks, having one or more holes that are open on both sides. The ingredients of HCB are cement, fine, course aggregate and water from those aggregate occupy more portion.

Many researchers done research on this ingredient is partially or totally replaced with different material to develop new construction or to improve quality of HCB and to get a sustainable source of aggregate. Sahul, (2014) Carried out a study that stable block is formed for 100% replacement of fine aggregate (sand) by stone dust. Foundry sand is replaced at various percentages of fine aggregate and stable block is formed by replacing fine aggregate (stone dust) by 2.5% foundry sand.

According to the Kumar (2008), the crushed sandstone known as reactive aggregate was used for both fine and coarse aggregates. Depending on such researcher's idea, the researcher was investigating the properties of HCB by replacing the scoria with the wastage of Ambo sandstone. Ambo sandstone is one type of stone categorized in sedimentary rock and which are found in the western part of the Ethiopia.

1.2. Statements of the problem

One of the most important ingredients of hollow concrete block is aggregate that differ depending on their classification. The most aggregate used for HCB are scoria and pumice. As many researchers conducted, the concrete produced from both aggregate were light weight and also the aggregate in HCB are partially or totally replaced with different type of material and wastage of some product to reduce the environmental pollution. According to Yılmaz (2012), Sandstones vary in composition and consequently when used in concrete as aggregate may cause different concrete strengths. According to the Kumar (2008), the crushed sandstone known as reactive aggregate was used for both fine and coarse aggregates. Mannan, (2001) and Mulu, (2003) carried out studies that crushed stone sand based on its quality, can replace 15 to 60% of total fine aggregate in concrete.

In Ethiopia the Ambo Sandstone is only used for decorative purpose of external wall. This mineral found in Ambo town and transport to every part of the country before dressed to the needed shape. After it arrives the irregular part is chiseled and unwanted part is stored as waste without any usage. Depending on wastage of some construction material, the researchers interested to conduct research to solve the problem and replace some wastage with in other ingredient to produce other alternative construction material.

Based on the finding of some scholars the researcher interested to study the relevance of hollow concrete block when the scoria replaced with wastage of Ambo sandstone and to know the percent replacement when it is used as combined aggregate.

1.3. Objective

1.3.1. General objective

The main objective of this study was to investigate the relevance of hollow concrete block produced as replacement of scoria with wastage of Ambo sandstone.

1.3.2. Specific objective

The specific objectives are:

- To determine the physical properties of wastage of Ambo sandstone aggregates and scoria.
- To determine the compressive strengths of hollow concrete blocks at different percentage replacement of wastage of Ambo sandstone; and
- To compare the production cost of hollow concrete blocks with and without wastage of Ambo sandstone.

1.4. Basic research question

1. Does the wastage of Ambo sandstone and scoria meet the physical properties requirement of aggregate for the production of HCB?

2. What are the compressive strengths of new produced HCB at different percentages replacement of wastage of Ambo sandstone?

3. Which one is more economical either HCB with or without Ambo sandstone?

1.5. Significance of the study

The significance of the findings is to provide the bench marks under which the wastage of Ambo sandstone used for the production of alternative construction material and to minimize the cost to buy other ingredient other than use the raw material from local. This research will benefit the construction participant who uses only the one ingredient for production of HCB and the society by generating additional income.

1.6. Scope of the study

The scope of this study was to investigate the relevance of hollow concrete block produced by replacement of scoria with wastage of Ambo sandstone. The research was needed in all part of the country because the waste of the Ambo sandstone is found everywhere, but the researcher limit the specific sampling location of Ambo sandstone around Ambo town.

This research was not conducted all relevance of the hollow concrete block produced with replacement of scoria with wastage of Ambo sandstone. The researcher conducted only the physical properties of aggregates and the compressive strength, water absorption, workability, density and production cost properties of hollow concrete block. Hollow concrete block produced in Ethiopia were three types depending on their dimension as 10 cm * 20 cm * 40 cm, 15 cm * 20 cm * 40 cm and 20 cm * 20 cm * 40 cm. Because of the availability and shortage of time the researcher limit study on 20 cm * 20 cm* 40 cm size of HCB

1.7. Limitation of the study

The Ambo sandstone mostly exists in boulders form, meaning that the rocks by its nature large in size. The usual scoria that has been used in production of hollow concrete blocks was somewhat finer than that of sandstone. Therefore, the researcher faces laborious work while converting the Ambo sandstone into required aggregate gradation.

CHAPTER TWO
LITERATURE REVIEW

2.1 General

Hollow concrete masonry units are ever more commonly used in masonry construction and hollow masonry units lower natural weight of masonry constructions; improve physical properties of walls, such as noise and thermal insulation (Bronius, 2013). The compressive behavior of masonry is crucial importance for design and safety assessment purposes, since masonry structures are primarily stressed in compression and these values can be obtained from tests on small assemblages or tests on the components(Mohamad, 2006).

Kaosol, (2010) had made study on the reuse of concrete waste as crushed stone for hollow concrete masonry units. The main objective was to increase the value of the concrete waste, to make a sustainable and profitable disposal alternative for the concrete waste. Attempts were made to utilize the concrete waste as crushed stones in the concrete mix to make hollow concrete blocks. Various percentages of crusted stones have been tried the amount (i.e. 0, 10, 20, 50 and 100%). From the results they found concrete waste can be used to produce hallow concrete block masonry units.

Echeta, (2013) had conducted study on the effect of partial replacement of granite with washed gravel on the characteristic strength and workability of concrete ,in which the granite was progressively replaced with washed gravel at intervals of 20% , from 0 to 100% replacement level the result show workability of the concrete decreased with increase in gravel content and as the percentage replacement level increased the compressive strength of the concrete increased to a maximum at 20% replacement level and it decreased as the replacement level increased to 100%.

Ahmad , (2012) an exploratory study on the suitability of the machine crushed animal bones as partial or full replacement for normal coarse aggregates in concrete works had been carried out. Compressive strength tests showed that approximately 50% of the crushed animal bones in replacement for normal aggregate were quite satisfactory with no compromise in compressive strength requirements for concrete mix ratio.

2.2 Materials for concrete

Concrete is one of the versatile and widely used building materials in the world construction industry. Fine and coarse aggregates make about 70% by volume of concrete production.

It goes without saying that the quality of concrete is thus strongly influenced by aggregate's physical and mechanical properties as well as chemical composition of the parent aggregate making material. This calls for a critical identification and classification of aggregates so that they are used to meet the intended purpose (Dinku,2005).

Dense concrete blocks, which may be hollow, cellular or solid in form, are manufactured from natural dense aggregates including crushed granite, limestone and gravel. Medium and lightweight concrete blocks are manufactured incorporating a wide range of aggregates including expanded clay, expanded blast furnace slag, sintered ash and pumice (Lyons, 2008)

2.2.1. Cement

Cement used in construction are sometimes named after their commonly reported place of origin, such as Roman cement, or for their resemblance to other materials, such as Portland cement, which produces a concrete resembling the Portland stone used for building in Britain (Belay, 2006).

Cement paste is the binder in concrete or mortar that holds the fine aggregate, coarse aggregate or other constituent's together in a hardened mass. The properties of concrete depend on the quantities and qualities of its constituents. Because cement is the most active component of concrete and usually has the greatest unit cost, its selection and proper use are important in obtaining most economically the balance of properties desired for a particular concrete mixture. Most cement will provide adequate levels of strength and durability for general use. It is usually satisfactory and advisable to use general-purpose cement that is readily obtainable locally. General-purpose cements are described in ASTM C 150. When such cement is manufactured and used in large quantity, it is likely to be uniform and its performance under local conditions will be known (ACI Committee, 1999).

According to Negash (2014), Portland cements are hydraulic cements composed primarily of hydraulic calcium silicates and hydraulic cements set and harden by reacting chemically with water. Hydration means when cement combines with water to form paste and added to aggregates it acts as an adhesive and binds the aggregates together to form concrete. Cement is a key to infrastructure industry and is used for various purposes and also made in many compositions for a wide variety of uses. Cements may be named after the principal constituents, after the intended purpose, after the object to which they are applied or after their characteristic property(Belay, 2006).

2.2.1.1 Types of Cement

Types of Portland cement can be varied by changing the relative proportions of its prominent chemical compounds, by the degree of fineness of the clinker grinding and/or by adding some pozzolanic materials. As a result, there are several types of cements for different purposes. Ordinary Portland cement (OPC), Rapid Hardening Portland cement, Sulphate Resisting Portland Cement, Low heat Portland cement, Portland Pozzolana Cement (PPC). But, only Ordinary Portland cement and Portland Pozzolana Cements are produced in Ethiopia (Aregaw, 2010).

A pozzolan is defined in ASTM C 618 as "a siliceous or siliceous and aluminous material, which in itself possesses little or no cementations value but which will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementations properties." They are composed of similar materials and react with the products of hydrating cement to create additional cementations binder. Glassy non-crystalline forms of silica, alumina, and iron are principally responsible for the pozzolanic reaction with calcium hydroxide (lime). In concrete, lime results from the hydration of Portland cement. Pozzolanic material can be used to modify and improve plastic and hardened properties of concrete.

AASHTO M 85, Specification for Portland cement, uses type designations I through V for Portland cement .Type I Portland cement is general-purpose cement suitable for all uses where the special properties of other types are not required. Its uses in concrete include pavements, floors, reinforced concrete buildings, bridges, tanks, reservoirs, pipe, masonry units, and precast concrete products (Aregaw, 2010). Type II Portland cement is used where precaution against moderate sulfate attack is important. It is used in normal structures or elements exposed to soil or ground waters where sulfate concentrations are higher than normal but not unusually severe. Type II cement has moderate sulfate resistant properties because it contains no more than 8% tri calcium aluminates (Aregaw, 2010).

2.2.2 Aggregate

Aggregates are the materials basically used as filler with binding material in the production of concrete and provide concrete with better dimensional stability and wear resistance.

They are derived naturally from igneous, sedimentary and metamorphic rocks or manufactured from blast furnace slag (Duggal, 2000).It is therefore significantly important to obtain right type and quality of aggregates (fine and coarse) because aggregates occupy 60 to 75% of the concrete volume (70 to 85% by mass) and strongly influence the concrete's freshly mixed and hardened properties, mixture proportions, and economy (Duggal, 2000).

Any aggregate with a particle density of less than 2000 kg/m3 or a dry loose bulk density of less than 1200 kg/m3 is defined as lightweight (Document, 1992) . However, this necessary dual qualification in definition highlights a practical difference from most other aggregates used in structural concrete where particle densities greater than 2000 kg/m^3 are used. In the case of an appropriate lightweight aggregate the encapsulated pores within the structure of the particle have to be combined with both the interstitial voids and the surface vesicles. Nevertheless, these features in combination should not increase the density of the compacted concrete either by significant water absorption or cement paste pervasion into the body of the aggregate particle when the aggregate is mixed into concrete (Clarke, 2005).

2.2.2.1 Classification of Aggregate

Depending on their weight aggregate can be classified as a) Normal weight aggregates b) Light weight aggregate c) Heavy weight aggregates. Normal weight aggregates can be further classified as natural aggregates and artificial aggregates as shown in table (Ngugi, 2014).

Table 2.1 Natural and artificial aggregates classification (Tamirat, 2016)

Natural	**Artificial**
Sand, gravel & crushed rock	Broken brick
Granite& Basalt	Air-cooled slag
Sandstone & Quartzite	Sintered fly ash bloated clay

2.2.2.2 Source of Aggregate

Almost all natural aggregate materials originate from bed rocks. There are three kinds of rocks, namely, igneous, sedimentary and metamorphic. These classifications are based on the mode of formation of rocks (Ngugi, 2014).

I. Igneous rocks

These are formed by the cooling of molten magma or lava at the surface of the crest (trap and basalt) or deep beneath the crest (granite) (Ngugi, 2014).The rate of this hardening has a large effect on these rocks; a rapidly cooling magma, or in this case more likely lava, will not have time to crystallize fully. As a result the rock is likely to be glassy, with few crystals.

On the other hand, a slow cooling magma will have more time to form crystals, and are likely to be highly crystallized. Also, particularly in rapidly cooling lavas, air in the lava can become trapped, as the lava hardens too quickly for it to escape. As a result, rocks formed this way often have many air voids in them (Kehew, 2006).

Most igneous rocks make highly satisfactory concrete aggregate because they are normally hard and dense. The most widespread of all the igneous rocks are basalts. Basalts are dark colored, fine grained extrusive rocks. The mineral grains are so fine that they are impossible to distinguish with the naked eye or even a magnifying glass. Most basalt is volcanic in origin and was formed by the rapid cooling and hardening of the lava flows. Some basalt is intrusive having cooled inside the Earth's interior (Addissie, 2005).

II. Sedimentary rocks

These are formed originally as a result of sedimentation of the broken down product of other rocks. The sedimentation usually takes place under water. The particles of the broken down rock can either be loosely joined, or cemented together (Kehew, 2006). Since sedimentary rocks are made from older rocks, their chemistry is usually simpler, and they are often more stable than the rock from which they were derived.

According to Fulton(2009), the quality of aggregates derived from sedimentary rocks will vary in quality depending upon the cementing material and the pressure under which these are originally compressed. Some siliceous sand stones have proved to be good concrete aggregate. Similarly, the limestone also can yield good concrete aggregate.

The thickness of the stratification of sedimentary rock may vary from a fraction of a centimeter to many centimeters. If the stratification thickness of the parent rock is less it is likely to show up even in an individual aggregate and thereby it may impair the strength of the aggregate. Such rocks may also yield flaky aggregates. The degree of consolidation, the type of cementation, the thickness of layers and contamination, are all important factors in determining the suitability of sedimentary rock for concrete aggregates (Addissie, 2005).

III. Metamorphic Rocks

Metamorphic rocks are formed through the transformation of other rock types. The transformation is usually due to high temperatures or high pressures (Kehew, 2006; Ngugi, 2014). It has been found that metamorphic rocks formed from sedimentary rocks have improved strength and durability than the original rock, while those formed from igneous rocks show little difference (Fulton, 2009).

Many metamorphic rocks particularly quartzite and gneiss have been used for production of good concrete aggregates (Addissie, 2005). The concrete making properties of aggregate are influenced to some extent on the basis of geological formation of the parent rocks together with the subsequent processes of weathering and alteration.

Within the main rock group, Say granite group, the quality of aggregate may vary to a very extent owing to changes in the structure and texture of the main parent rock from place to place (Ngugi, 2014).

2.2.2.3 Locally available aggregates

I. Basalt

Basalts are dark colored, fine-grained extrusive rock. The mineral grains are so fine that they are impossible to distinguish with the naked eye or even with a magnifying glass. They are the most widespread of all the igneous rocks. Most basalt is volcanic in origin and was formed by the rapid cooling and hardening of the lava flows. Some basalt is intrusive having cooled inside the Earth's interior (Dinku, 2005)

II. Pumice

Pumice is a very light, porous igneous rock that is formed during volcanic eruptions. It is an excessively cellular, glassy lava, usually rhyolite or dacite in composition. It is usually white-gray to yellow in color, but may be red, brown or sometimes black according to the mineral oxides or impurities it contains. Pumice is bubble rich and therefore has very low density.

Due to this low density, pumice is very light and can even float in water. It has a bulk density of 500-900kg/m^3. The varieties of pumice, which are not too weak structurally, make a satisfactory concrete with a density of 700 to 1400kg/m^3 and with good insulating characteristics, but high absorption and high shrinkage characteristics (Dinku, 2005).

III. Scoria (red ash)

The suitability of using scoria as both fine and coarse aggregate in lightweight concrete production is assessed and compared with other lightweight aggregates. The properties of scoria concrete are evaluated by conducting comprehensive series of tests on workability, air content, density, strength, drying shrinkage, and water permeability. Finally Scoria concrete shows good heat-insulating characteristics and can be used in building construction as an energy saver (Hossain, 2006).

The overall clay lumps content in the SA was determined according to ASTM C331 mm in dimensions, were prepared from these paste mixes.The change in length of the test specimens was calculated by subtracting the length comparator reading before autoclaving from that after autoclaving, and reported as percent of effective gage length to the nearest 0.01 %. According to Yohannes (2015), experimental investigations showed that ribbed-slabs can be constructed using scoria aggregates with 40 - 47% fine content, 1.6 – 1.8 A/C ratios and 0.4 W/C in range of normal cement content and scoria was used as both coarse and fine aggregate in the manufacture of scoria-scoria concrete.

According to Hossain (2006), Scoria has the potential to be used as an additive to PC for the manufacture of blended cement like other pozzolanic materials such as fly ash and volcanic ash. Scoria can be utilized in several industrial applications including the manufacturing of lightweight concrete, as a source of pozzolan to manufacture Portland-pozzolan cement additive, as a heat insulating materials, in addition to other uses such as low cost fillers, filter materials, absorbents and other architectural applications. Scoria is locally used in road construction as sub-base material and there are several quarries operating on scoria deposits in highland provinces.

The concrete produced from a mix combination of cement, fine aggregate (sand) and volcanic scoria as coarse aggregate. The produced concrete tested for compressive strength, flexural strength and water absorption capacity and the result of compressive and modulus ruptures for 28-days was 20.42 N/mm^2 and 6.08 N/mm^2 respectively. The result shows that scoria concrete has sufficient strength to be used as a construction material (AHO, 2015:).

Yohannes (2015) concluded that, structural scoria lightweight concrete can be produced up to strength of 30 MPa by using locally available well-graded scoria coarse and fine aggregates with cement content of 360 kg/m^3 and above.

And also mix proportions of scoria coarse aggregates with scoria fine aggregates possessed a desirable quality with regard to strength; therefore, scoria concrete with 40 - 47% fine content, 0.45 water cement ratio and 400 kg/m^3 of cement content can be used for ribbed slab construction.Scoria is heavier than pumice and darker because it contains more iron. It is usually found closer to the volcano's crater than pumice. Scoria is a reddish-brown or grey rock that can be crushed and used in garden paths or as a drainage material around pipes.

Iv. Sandstone

The characterization and identification of minerals is fundamental in the development and operation of mining and minerals processing systems, worldwide sandstones have been used as construction material for centuries (Mubiayi, 2013).The composition of sandstone is quite similar to that of sand that essentially consists of quartz.

The natural cementing material which binds the sand together as rock is usually composed of silica, calcium carbonate, or iron oxide. Crushed sandstone known as reactive aggregate was used for both fine and coarse aggregates. In addition, mineral admixtures such as silica fume and fly ash combined with super plasticizer was used (Kumar,2008). Sandstone is a classic sedimentary rock comprising an aggregate of sand sized (0.06–2.0-mm) fragments of minerals, rocks or fossils held together by mineral cement. Actually, sandstone forms when sand is buried under successive layers of sediment. During burial the sand is compacted and a binding agent such as quartz, calcite or iron oxide is precipitated from ground water which moves through passageways between grains to create Sandstone (Romi, 2012).

According the Kumar(2016), test results of three average values for water cement ratios of 0.35, 0.4 and 0.45, the compressive strength showed a decreasing trend whilst adding quartz sandstone as coarse aggregate. Upon 100 % replacement, a maximum of 21 % decrease in compressive strength was observed at 0.45 water/cement ratio. However, a maximum decrease of only 8 % in compressive strength was observed up to 40 % substitution when compared with the control concrete and also as the percentage of replacement of quartz sand stone increase the flexural strength decrease.

Jeng,(2003) found that sandstones differ from hard rocks in having significant shear dilation and wetting softening behavior, which is defined as the reduction of both strength and stiffness of dry sandstone due to wetting. Such distinct behavior can occur even when the sandstones have medium to moderate strength.

Sandstone is generally composed of grains of quartz and other minerals of fairly uniform size which are often smooth and rounded. These grains are held together by a cementing material which may be siliceous or ferruginous. The toughness of sandstone depends mostly on the nature of this cementing material. While utilizing sandstone into concrete, different properties of sandstones has to be studied in detail to know the potential use of sandstone as a part or whole replacement of coarse aggregates (Kumar, 2016)

According to Hsieh (2008), the wet-softening behavior of sandstones refers to the reduction of shear strength when the material is wetted by water. This wet softening behavior is owing to the fact that the bonding strength of matrix materials is reduced when the sandstone is wetted. Sandstones being a sedimentary type of rock are composed of sand-sized mineral grains, rock fragments and pieces of fossils which are held together by mineral cement. They differ from other igneous rocks in possessing a framework of grains that touches each other but not in continuous contact. Quartz being a mineral which is highly resistant to both physical and chemical weathering is also found in sandstones. Being found in sandstones, they can be used as partial replacement of aggregate in cement concrete (Kumer, 2016)**.**

Macroscopic mechanical properties of sandstones, such as uniaxial compressive strength and Young's modulus were found to be significantly affected by their petrographic properties, e.g. the porosity n and the grain area ration (Hsieh, 2008).

2.2.2.4 Physical Properties of Aggregate

Most properties of aggregate depends on the properties of parent rock e.g. chemical and mineral composition, petrographic classification, specific gravity, hardness, strength, physical and chemical stability, pore structure, color, etc. in addition, there are properties of aggregate absent in the parent rock: particle shape and size, surface texture and moisture content. All properties may have a considerable influence on the quality of fresh or hardened concrete (Neville, 1999)

2.3. Hollow Concrete Blocks (HCB)

Cement concrete hollow blocks have an important place in modern building industry. They are cost effective and better alternative to burnt clay bricks by virtue of their good durability, fire resistance, partial resistance to sound, thermal insulation, small dead load and high speed of construction.

Concrete hollow blocks being usually larger in size than the normal clay building bricks and less mortar is required, faster of construction is achieved (Thorat, 2015).Hollow concrete masonry units are ever more commonly used in masonry construction and lower natural weight of masonry construction; improve physical properties of walls, such as noise and thermal insulation. Hollow masonry units of a special construction solution can be used as a residual mould (Bronius, 2013).

Hollow concrete block have become a regular or frequent choice today in construction activities as these blocks offer various benefits, simplicities in their use as building elements, strength comparable with the conventional blocks like bricks, facilities to get reinforced thereby increasing the strength of constructed units, facility for better finish, adoptability for getting desired architectural shapes and beauty and above all rendering economy in construction (Thorat, 2015).

According to ES 596 (2001),HCB is an alternative wall and floor making material in the building construction having one or more large holes with the solid material between 50%-75% of the total volume of the block calculated from the overall dimensions. On the other hand according to (Concrete Block Association, 2007), blocks which contains one or more formed voids which are fully penetrate the block, decrease in density, thus decreasing the end-product weight.

2.3.1. Classification of hollow concrete blocks in different standards

A) Based on Ethiopian standard [ES 596:2001].

According to ES 596 (2001), hollow concrete blocks shall meet four classes depending on their compressive strength, as class A, class B, class C and D

Class A: are load bearings
Class B: are also load bearings Class
Class C: are also load bearing
Class D: are used for non-load bearing

Table 2.3 (A1). Comprehensive strength of hollow concrete blocks at 28 days [ES 596:2001]

Type of HCB	Class	Minimum compressive strength (N/mm2)	
Load bearing		Average of 6 unit	Individual units
	A	5.5	5.0
	B	4.5	4.0
	C	3.5	3.0
Non load bearing	D	2.0	1.8

Table 2.3(A2) Nominal dimensions of hollow concrete blocks **(ES 569:2001)**

Length (mm)	Breadth (mm)	Height (mm)
400	100 150 200	200
500	100 120 150 200	100 150 200 250
600	100 120 150 200	100 150 200 250

The standard also list nominal size of hollow concrete blocks in terms of length, breadth and height as shown above in Table 2.3(A2). For each length class the standard list possible breadth and heights. Among the listed dimensions the length class 400 mm is only considered as modular with different breadth (100 mm, 150 mm and 200 mm) and a height of 200 mm.

B) Based on American Society for Testing and Materials

According to ASTM C90-70 and ASTM C129-70 hollow concrete blocks are mainly classified as load bearing and non- load bearing in terms of compressive strength. The classification is listed in Table 2.3(B) as shown below.

Table 2.3(B) Compressive strength of hollow concrete blocks (ASTM C90-70) and (ASTMC-129-70)

Type of hollow concrete block	Grade	Minimum compressive strength (N/mm2)	
		Average of 3 units	Individual units
Load bearing	Type N (I and II)	6.9	5.5
	Type S (I and II)	4.8	4.1
Non load bearing	(type I and type II)	Average of 5 units	Individual units
		3.5	3.0

As shown in Table 2.3(B), ASTM classifies hollow concrete blocks as load bearing and non-load bearing. There are two grades under load bearing these are type N and type S. grade N are used for general use such as in exterior walls below and above grade level. Grade S are used only above grade level. Both grades have two types such as moisture controlled units known as Type I and non-moisture controlled units known as type II. The non-load bearings are also grouped under type I and type II.

2.3.2 Manufacturing process of HCB

According to GTZ (2011) ,the process of manufacture of cement concrete hollow blocks involves the following 4stages

Stage1: Proportioning

Stage2: Mixing

Stage3: Compaction

Stage4: Curing

Stage1Proportioning

The determination of suitable amounts of raw materials needed to produce concrete of desired quality under given conditions of mixing, placing and curing is known as proportioning. The combined aggregate content in the concrete mix used for making hollow blocks should not be more than 6 parts to 1 part by volume of Portland cement.

If this ratio is taken in terms of weight basis this may average approximately at 1:7 (cement: aggregate). However, there have been instances of employing a lean mix of as high as 1:9 by manufacturers where hollow blocks are compacted by power operated vibrating machines. The water cement ratio of 0.62 by weight basis can be used for concrete hollow blocks.

Stage2: Mixing

The objective of thorough mixing of aggregates, cement and water is to ensure that the cement-water paste completely covers the surface of the aggregates. All the raw materials including water are collected in a concrete mixer, which is rotated for about 1 ½ minutes. The prepared mix is discharged from the mixer and consumed within 30 minutes.

Stage3: Compaction

The purpose of compacting is to fill all air pockets with concrete as a whole without movement of free water through the concrete. Excessive compaction would result in formation of water pockets or layers with higher water content and poor quality of the product. Semi-automatic vibrating table type machines are widely used for making cement concrete hollow blocks. The machine consists of an automatic vibrating unit, a lever operated up and down metallic mould box and a stripper head contained in a frame work. Wooden pallet is kept on the vibrating platform of the machine. The mould box is lowered on to the pallet. Concrete mix is poured into the mould and evenly leveled. The motorized vibrating causes the concrete to settle down the mould by approximately 1 ½ to 1 ¾ inches. More of concrete is then raked across the mould level. The stripper head is placed over the mould to bear on the leveled material. Vibration causes the concrete come down to its limit position and then the mould box is lifted by the lever. The moulded hollow blocks resting on the pallet is removed and a new pallet is placed and the process repeated. The machine can accommodate interchangeable mould for producing blocks of different sizes of hollow or solid blocks.

Stage4: Curing

Hollow blocks removed from the mould are protected until they are sufficiently hardened to permit handling without damage. This may take about 24 hours in a shelter away from sun and winds. The hollow blocks thus hardened are cured in a curing yard to permit complete moisturisation for at least 21 days. When the hollow blocks are cured by immersing them in a water tank, water should be changed at least every four days.

The greatest strength benefits occur during the first three days and valuable effects are secured up to 10 or 14 days. The longer the curing time permitted the better the product.

2.3.3 Workability of hollow concrete blocks

The strict definition of workability is the amount of useful internal work necessary to produce full compaction and the useful internal work is physical property of concrete alone and is the work required to overcome the internal friction between the individual particles in the concrete. Term used to describe the state of fresh concrete is consistence which is the firmness of form of a substance or the ease with it will flow, in case of concrete consistence is sometimes taken to mean the degree of wetness; within limits, wet concretes are more workable than dry concrete, but concretes of the same consistence may vary workability (Brooks, 2010).

Workability depends on a number of interacting factors:water content,aggregate type and grading,aggregate/cement ratio,presence of admixtures and fineness of cement.The main factor is the water content of the mix since by simply adding water the interparticle lubrication is increased. The stiffening of concrete is effectively measured by a loss of workability with time, known as slump loss, which varies with richness of the mix, type of cement, temperature of concrete and initial workability (Chiemela, 2015).

Change in apparent workability or consistence and because we are really interested in the workability at the time of placing ,i.e. sometime after mixing ,it is preferable to delay the appropriate test until 15 minutes after mixing. A higher temperature reduces the workability and increases the slump loss. In practice, when the ambient conditions are unusual, it is best to make actual site tests in order to determine the workability of the mix (Brooks, 2010).

According to ASTM C143 (2005), the mould for the slump test is a frustum of a cone, 305 mm (12 in.) high, base of 203 mm (8 in.) and diameter is placed on a smooth surface with the smaller opening of 102 mm (4 in) diameter at the top, and the container is filled with concrete in three layers. Each layer is tamped 25 times with a standard 16 mm (5/8 in) diameter steel rod, rounded at the end, and the top surface is struck off by means of a scree ding and rolling motion of the tamping rod. The mould must be firmly held against its base during the entire operation; this is facilitated or foot-rests brazed to the mould. Immediately after falling, the cone is slowly lifted, and the unsupported concrete will now slump hence the name of the test.

The decrease in the height of the Centre of the slumped concrete is called slump, and is measured to the nearest 5 mm (1/4 in.). In order to reduce the influence on slump of the variation in the surface friction, the inside of the mould and its base should be moistened at the beginning of every test, and prior to lifting of the mould the area immediately around the base of the cone should be cleaned from concrete which may have dropped accidentally.

2.3.4 Water absorption of hollow concrete blocks

According to Kahsay (2014), water absorption is a measure of the voids within the net volume of the concrete, including the voids within the aggregate itself. According to ASTM C140-70, the water absorption determined from five full-size units by completely immersed in water at room temperature for 24 hours and they shall be removed from the water and allowed to drain for one minute by placing them on a 10 mm or coarser wire mesh, visible surface water being removed with a damp cloth, and immediately weighed and then all specimens shall be dried in a ventilated oven at 100 °C to 115 °C for not less than 24 hours and until two successive weightings at intervals of 2 hours show an increment of loss not greater than 0.2 percent of the last previously determined mass of the specimen and the recommended Water Absorption requirements of load bearing Hollow concrete block in the table 2.4. On the other hand Ethiopian standard [ES 596:2001] specify water absorption 290 kg/m3 (25%) for load bearing hollow concrete block and 320 kg/m3 (30%) for non-load bearing hollow concrete block but Indian standard recommended 10 percent.

Table 2.4 Absorption requirements of load bearing HCB [ASTM C90-70]

Grade	Water absorption max (kg/m3)			
	Oven dry weight Classification (kg/m3)			
	Light weight		Medium weight	Normal weight
	>1362 (kg/m3)	1362±1682 (kg/m3)	1682-2002 b(kg/m3)	< 2002 (kg/m3)
N-I & II	-	290	240	210
S-I & II	320	-	-	-

2.3.5 Compressive strength of hollow concrete blocks

The strength of a material is defined as the capability of the material to resist stress without failure (Fulton, 2009). The strength of hardened concrete is fundamental in structural design, and is widely used as an index to predict other concrete properties.

The compressive strength of concrete is one of the most important and useful properties of concrete. The primary purpose for design concrete is to resist compressive strength in structural members, in general is the characteristic material value for classification of concrete. Strength of concrete is the commonly considered its most valuable property, although in many practical cases other characteristic ,such as durability and impermeability , may in fact be more (Chiemela, 2015).

However, strength usually gives an overall picture of the quality of concrete because strength is directly related to the structure of the hardened cement paste (Neville, 1999).The compressive strength of conventionally manufactured hollow concrete blocks that are available at Mysore varies from 3.2 to 3.7 MPa (Sureshchandra, 2014).

2.3.6 Production cost analysis of hollow concrete blocks

According to Luca C (2008) and Calin (2003), the production cost of are classified into direct and indirect cost. The direct cost includes material, labor and equipment cost.

2.3.6.1 Direct cost of production

Direct costs are costs that are traceable and they are costs related only to that product. They can be direct cost of materials, labor and equipment that are directly involve in the production process. Direct costs are costs that can be specially booked with an activity

2.3.6.1.1 Direct cost of materials

The total cost of materials required to perform a unit of activities in a project. Material costs are obtained by getting quotations from suppliers, generally in a unit price of dollars per unit of measure of a specified material. Many unit prices may be provided for the same material depending on the volume of purchase at a given time

2.3.6.1.2 Direct cost of labor

Labor costs in construction are determined by two factors: monetary and productivity. The monetary factor is related to hourly wage rates, wage premiums, insurance, fringe benefits, and taxes. Estimating the components of the monetary factor is more difficult in construction than in any other US industry. This is due to the variety of work involved in construction, as well as the many types of trades involved. The problem is further complicated by the presence of the unions with their craft structures and collective bargaining processes. Although the computational process of this component seems complex and tedious, it is only a matter of accounting as the needed numbers (such as wage rates, fringe benefits, and insurance) are readily available. The second factor, which is much more difficult to deal with, is productivity. In the most general sense, productivity is the ratio of input versus the respective output

According to Calin M (2003)

$$\text{Productivity} = \frac{\text{Quantity of work produced}}{\text{Time duration}} \quad \text{......2.1}$$

$$\text{Utilization factor} = \frac{1}{\text{Crew production (out put)}} \quad \text{......2.2}$$

$$\text{Labor unit cost} = \text{Utilization factor} * \text{Wage rates (daily or hourly)} \quad \text{......2.3}$$

2.3.6.1.3 Direct cost of equipment

The initial cost is the total cost a contractor pays to purchase a piece of equipment and have it shipped to a jobsite or equipment yard. This initial cost is the basis for determining other costs related to ownership as well as operating costs. Renting construction equipment is an increasingly popular procurement method. The primary advantage in renting equipment is the ability to procure the right piece of equipment for the job when the unit is needed.

Renting allows for more specific equipment selection as more choices are usually available from renters than the contractor's presently owned fleet. Using owned equipment also encourages inefficiency through use of the wrong size or type of unit for a given job. Renting can eliminate that problem. Equipment rental rates vary throughout the country with larger cities normally having lower rates. Most rental companies calculate their rates on a monthly basis. Monthly rental rates vary from 2 to 5% of the cost of equipment.

Direct unit cost of equipment is the product of number of equipment used the utilization factor and rental rates (monthly or daily).

$$\text{Direct unit cost of equiment} = \text{Number of equipment} * \text{Utilization factor Rental rates} \quad 2.4$$

$$\text{Utilization factor} = \frac{1}{\text{Equipment out put(annual or daily)}} \ldots\ldots 2.5$$

2.3.6.2 Indirect cost of production

Indirect costs of production are common cost and they are all costs which cannot be directly booked under a specific activities but they are required to keep the whole projects operational. This are also called overhead costs, head office and site overhead costs.

$$\text{Direct cost} + \text{In direct cost} = \text{Total production cost} \ldots\ldots 2.6$$

CHAPTER THREE

METHODOLOGY AND MATERIALS

3.1 Sampling Location

The sample of wastage of Ambo sandstone was taken form Ambo town and which located in the West Shewa Zone of the Oromia Regional national state, west of Addis Ababa at 125 km. This town has latitude of 8°59′N and longitude 37°51′E and an elevation of 2101 meters and the experiment was conducted in Jimma Construction material Laboratory.

Figure 3.1 Map of Ambo

3.2 Research Design

The research design was based on a purposive sampling selection process in terms of which a representative sample of HCB which partially replaced scoria with wastage of Ambo sandstone. The methodology used in the research was laboratory analysis of sample data, and collected sample from the site. The laboratory test have been taken for aggregate were gradation, unit weight, bulk specific gravity, absorption, moisture content, clay slump and compressive strength for HCB.

After widely organizing literature review of different previous published researches of hollow concrete block, then sample preparations at different Percentage of wastage of Ambo sandstone with scoria. According to the Mannan (2001) and Mulu (2003) carried out studies that crushed sandstone based on its quality, can replace 15 to 60 % of total fine aggregate in concrete. Based on this finding the researcher interested determines the properties of HCB if the percentage of replacement of sandstone varies with 20% interval.

The ratio of replacement of wastage of Ambo sandstone to scoria 0:100, 20:80, 40:60, 60:40, 80:20 and 100:0. Finally the produced hollow concrete blocks compressive strength tests have been carried out at age of 7th, 14th and 28th day with relative to standard specification of hollow concrete blocks for each ratio.

3.3 Sample Size and Selection

The study followed on a purposive sampling selection process. For aggregate laboratory test, the samples were dependent on the types of test requirement and standards. For each tests quartering and weighting will be used for sampling technique.

The output of the study was to determine the engineering properties and cost efficiency of the HCB with and without wastage of Ambo sandstone and to justify suitable percentage replacement of scoria with wastage of Ambo sandstone. To determine the sample size of test it needs standards and specifications.

According to Ethiopia standards ES: 596 (2001), it requires minimum of 6 samples of HCB with mold size of (400 mm * 200 mm * 200 mm). Since, the characteristic strength of hollow concrete block was usually measured by using compressive strength test at different age. For this study the researcher had the following at 7th, 14th, & 28th day with total of 108 samples shall been taken.

3.4 Study variables

In this study the relevance of hollow concrete blocks as the dependent variable and bulk specific gravity, moisture content, absorption, Unit weight, percent of replacement and gradation are the independent variable.

3.5 Sources of Data

Both primary data sources and secondary data sources haven been used. Secondary data needed for this research will be collected from different journals, book, website etc. During the literature review and primary sources of data for this study are laboratory experimental output.

3.5.1. Materials and equipment/tools

Generally scoria, ordinary Portland cement, 01 crushed aggregates and wastage of Ambo sandstone were materials used in this study.

a) Materials for hollow concrete blocks

Materials used to produce HCB were:

- Capital Ordinary Portland cement(OPC)
- 01 Crushed aggregates
- Scoria
- Wastage of Ambo sandstone
- Water

- **Cement Used**

Type of Cement used in the production of HCB was 'Capital'- Ordinary Portland cement (OPC) the Cement Grade 42.5 which is local available cement..

- **Aggregates Used**

Aggregates are materials basically used as filler with binding material in the production of hollow concrete block. Aggregates form the body of the hollow concrete block, reduce the shrinkage and affect economy. Therefore, it is significantly important to obtain right type and quality of aggregates on site. They should be clean, hard, strong, and durable and graded in size to achieve utmost economy from the paste. Therefore, to judge the quality of the aggregate physical characteristics tests have to be conducted. So, in this research the following physical testes are performed on the properties of 01 aggregate size which is basically used for the production of HCB. The 01 aggregate used for this research was basaltic crushed rock. The size of aggregate used for experimental investigation was a maximum size of 12.5 mm diameter aggregate was used.

- **Scoria used**

Scoria is one type of light weight aggregate used for the production of the hollow concrete block. The scoria used in this research was red scoria and the size is combination of the fine and coarse aggregate. The maximum size of the scoria was 12.5 mm diameter. Therefore to get the maximum size of scoria needed for production of HCB the scoria was sieved with sieve size of 12.5 mm.

❖ **Wastage of Ambo sandstone used**

Sandstone is the classified under the sedimentary rock which is formed from the sediment materials. Sandstone is found in Ethiopia in the north part and in some west such like Ambo. As its name indicate the wastage of Ambo sandstone taken from the name the town Ambo. The wastage of Ambo sandstone was taken from sankale quarry site; it was crushed to the needed size and sieved with 12.5 mm sieve size.

❖ **Water Used**

Mixing water used for all the mixes in this research was drinkable water (potable water).

b) Equipment and tools used for HCB production

The tools used to conduct the experiment in laboratory are such as metal tray, balance, oven dry, metal container, wire basket, shovel, specific gravity machine, egg laying machine and compressive strength testing machine.

❖ **Egg-laying**

Concrete blocks can be molded by several methods, ranging from manually tamping the concrete in wooden or steel mold boxes to large scale production with "egg laying" mobile machine and fully automatic stationary machine. Egg-laying mobile machines are designed for medium-scale production, either on-site or in a factory. The name was given to these machines, because they leave the blocks to dry where they are produced on a flat production surface and move a short distance away to produce the next batch of blocks, and so on. The quality of blocks generally increases with the degree of mechanization, but medium standards are normally adequate for most construction purposes. Therefore the equipment used in this research was egg laying mobile machine.

3.5.2. Determining physical properties of aggregate for hollow concrete block

The physical properties of all aggregate necessary for describing the type of aggregate used and also properties that can affect the production of HCB were determined prior to production. The test methods used for the aggregates are listed in Table 3.1

Table 3.1 Property tests and test methods

Property tests	**Test methods**
Gradation(crushed aggregate , scoria and Ambo sandstone)	ASTM C136 and 331
Unit weight (crushed aggregate , scoria and Ambo sandstone)	ASTM C29
Clay slumps(scoria and Ambo sandstone)	ASTM C142
specific gravity and absorption (crushed aggregate , scoria and Ambo sandstone)	ASTM C127
Moisture content (crushed aggregate , scoria and Ambo sandstone)	ASTM C 566

The samples for the property test were taken from the production site by using quartering method. And the results for the tests are presented in the data sheets in **Appendix one.**

3.5.3 Production of hollow concrete blocks

Producing the hollow concrete blocks was conducted by following different production steps.

3.5.3.1 Proportioning the materials

The two most widely used cement to aggregate ratios are 1:6 and 1:8 for hollow concrete blocks production (SRCCD, 2008). In the study area which is Ambo town the micro and small enterprises use cement to aggregate ratio of 1:6.Which means the 1:4:2 ;1 bag of cement to 4 boxes of scoria and 2 boxes of 01 crushed aggregate. The mix proportion used by the micro and small enterprises was taken from GTZ Low Cost Housing Manual Volume I. Therefore based on their mix proportions the researcher interested to replace the wastage of Ambo sandstone instead of scoria in this proportion. The proportioning box used was the box which is commonly used for HCB proportioning, that is 20 cm x 40 cm x 50 cm (height, width and length). There was a need to prepare another box to measure the 20% replacement. Which means the standard box measure 0.04 m^3 and the 20% of 0.04 m^3 was 0.008 m^3.Then the new box was prepared by (10 cm * 20 cm * 40 cm) dimension to replace the needed amount.


Figure 3.2(a) 10 cm * 20 cm * 40 cm box (b) 20 cm * 40 cm * 50 cm box

The proportion used by micro and small enterprise in Ambo town to produce HCB is 1:4:2. That is cement, scoria and crushed aggregate proportion. Based on this proportion the researcher was replace ratio of scoria with different percentage replacement of wastage of Ambo sandstone. According to the Mannan (2001) and Mulu (2003) carried out studies that crushed sandstone based on its quality, can replace 15 to 60 % of total fine aggregate in concrete. Based on this finding the researcher interested determines the properties of HCB if the percentage of replacement of sandstone varies with 20% interval. And out of the six part of aggregate it replaced the amount of scoria with different percentage of wastage of Ambo sandstone with a constant interval of 20 % and increased up to 100%. This was done in order to determine the maximum replacement of wastage Ambo sandstone instead of scoria. The proportion for the HCB was prepared by using the 10 cm x 20 cm x 40 cm boxes as follows: 100% wastage of Ambo sandstone means 20 boxes by using 10 cm x 20 cm x 40 cm boxes. This means the volume of box is 0.04 $m^3$and the 20% volume of this box is 0.008 m^3. But the total amount of replaced was 4 boxes depending on the mix ratio. Since the volume of four boxes of 20 cm x 40 cm x 50 cm is 4*0.04m^3 = 0.16 m^3 which is also equals to the volume of 20 boxes with 10 cm x 20 cm x 40 cm (i.e. 20 * 0.008 m^3) = 0.16 m3, 0.008 m^3 is the volume of 10 cm x 20 cm x 40 cm box). In this step the amount of cement and crushed aggregate are constant according to mix ratio

The different percentages of wastage of Ambo sandstone and scoria which were used are tabulated in Table 3.2

Table 3.2 Different percentages of scoria and wastage of Ambo sandstone used

Sample ID.	No. of(10 cm * 20 cm * 40 cm) box		Percent	
	Scoria(box)	Wastage of Ambo sandstone(box)	Scoria (%)	Wastage of Ambo sandstone (%)
1	20	0	100	0
2	16	4	80	20
3	12	8	60	40
4	8	12	40	60
5	4	16	80	20
6	0	20	0	100

After proportioning of the scoria and Wastage of Ambo sandstone, the materials were placed in sacks and recorded with the percentage of wastage of Ambo sandstone content. Then it transported to the manufacture place.

3.5.3.2 Mixing process

The mixing process was conducted inside electrically operated mixer which is directly connected to batching box. Before this stage all ingredients of HCB was batched by determined ratio and placed in the prepared batching container.

The first step was dry mix of aggregates (wastage of Ambo sandstone/scoria/01 crushed aggregate) and cement by mixer. Then the water was added to the dry mixed ingredient by the machine with adjusted water cement ratio. The selected water cement ratio for the HCB was 0.5, which is between (0.49- 0.55) that was recommended by GTZ Low Cost Housing Manual Volume I. In case of this study water cement ratio for the HCB was found between 0.5 - 0.49, because the wastage of Ambo sandstone less water absorptive than scoria.

3.5.3.3 Molding process

After the mixing process was taken in the previous stage the molding was under taken in this stage. In this stage the properly mixed ingredients was transported by conveyor to the store packet until it full and then pass to the mold maker machine.

The material was added to molder was vibrated by table vibrate and the load was applied on the material found in the mold for 45minutes then the load was released by producing the hollow concrete blocks.

3.5.3.4 Curing process

After the hollow concrete blocks was taken from the molding machine it was stored under the shade, and then kept for 24 hours without removing the plate under wet mold .Finally after 24 hours the plate was removed and cured regularly for 7days by spraying water.

3.5.4 Compressive strength test and production cost calculation

Compressive strength test was carried out on the blocks prepared to determine the compressive strength at each percent and maximum compressive strength at optimum replacement of Ambo sandstone. Compressive strength test of 7^{th}, 14^{th} and 28^{th} day were conducted according to ES 596:2001 after regularly cured by spraying water for 7 days. The production cost calculation was conducted based on direct unit production costs for both hollow concrete blocks with and without wastage of Ambo sandstone in order to compare the production costs.

3.6 Data processing and analyzing

To meet the research objectives, in this part to analyze the engineering properties of hollow concrete block produced by partial replacement of scoria with wastage of Ambo sandstone.

3.6.1. Analyzing the compressive strength

The compressive strength of HCB produced with different replacement of wastage of Ambo sandstone was conducted by taking the mean of six HCBs as stated in the procedure of Ethiopian standard (ES 596:2001).

The mean compressive strengths of HCB with different wastage of Ambo sandstone were analyzed with different standards. According to ASTM(C 90-70) and (ASTM C-129-70) average of 3 and 5 HCBs are required. Therefore, the compressive strengths were computed according to Ethiopian standard (ES 596:2001) and the results were analyzed and presented in tables and graphs.

3.6.2. Production cost analysis

The cost of producing both blocks was analyzed by considering the cost of material, manpower and machinery. Because according to this study the production cost was varied only with the cost of material but the cost of the machinery and man power were constant.

3.6.2.1 Unit cost of materials*:*

The materials cost used for analysis was taken from the current local market and the quantity of each material was calculated from the mix ratio of the 1:4:2 of hollow concrete blocks by the rate analysis method. The quantity of material was calculated from the ratio of the mix which means the ratio produce 16 hollow concrete blocks according to the micro enterprise in the study area. The size of the box used was 20 cm * 40 cm* 50 cm which is equal to 0.04 m^3 and the ratio indicated 1cement ,4 boxes scoria/wastage of Ambo sand stone and 2 boxes 01 crushed aggregate, to determine the total volume for each material multiply volume of box by number of ratio but not for cement. Then dived the total volume of each material for total amount of hollow concrete block produced by mix ratio which means 50kg cement,0.16 m^3scoria or wastage of Ambo sandstone and 0.08m^3 01 crushed aggregate divide to 16 HCB. The quantity of the materials were calculated in table 3.3(a) as follow

Table 3.3 (a) the quantity of material per hollow concrete block

Materials of HCB	Quantity of material in 1:4:2 mix ratio(A)	Quantity of material in One HCB (A/16HCB)
Cement (kg)	50	3.125
Scoria/wastage of Ambo sandstone(m^3)	0.16	0.01
01 crushed aggregate(m^3)	0.08	0.005

Table 3.3(b) quantity of material per hollow concrete blocks with different replacement

Percent of replacement (%)	Quantity of material per hollow concrete block			
	Cement(kg)	Scoria(m^3)	Wastage of Ambo sandstone (m^3)	01 crushed aggregate(m^3)
0	3.125	0.01	0	0.005
20	3.125	0.008	0.002	0.005
40	3.125	0.006	0.004	0.005
60	3.125	0.004	0.006	0.005
80	3.125	0.002	0.008	0.005
100	3.125	0	0.01	0.005

3.6.2.2 Unit cost of labor

The unit cost of labor was analyzed by considering utilization factor, daily wage and number of labor used to produce.

$\text{Utilization factor} = \frac{1}{\text{Crew production (out put)}}$, the crew daily production in Ambo town for producing HCB is 1500 blocks per day.

$$\text{Labor unit cost} = \text{Number of labor} * \text{Utilization factor} * \text{hourly cost}$$

3.6.2.3 Unit cost of equipment

The direct unit cost of equipment was analyzed by considering daily rental cost, number of equipment used and utilization factor.

$\text{Utilization factor} = \frac{1}{\text{Equipment out put(annual or daily)}}$, the daily production considered is 1500 blocks per day.

$$\text{Direct unit cost of equiment} = \text{Number of equipment} * \text{Utilization factor} * \text{Rental rates}$$

$$\text{Direct cost} + \text{In direct cost} = \text{Total production cost}$$

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Physical Properties of aggregates for production of Hollow concrete block

To specify the type of materials used in this research and to check whether the materials used are recommended by available standards and documents regarding to hollow concrete blocks production, physical properties tests of materials were conducted and the detailed data sheets with results are attached on **appendix one** of this thesis.

4.1.1 Physical property tests on scoria

4.1.1.1 Sieve analysis of scoria

The test method used was (ASTM C136) and the detailed result obtained is attached on appendix one on table 1A**.**

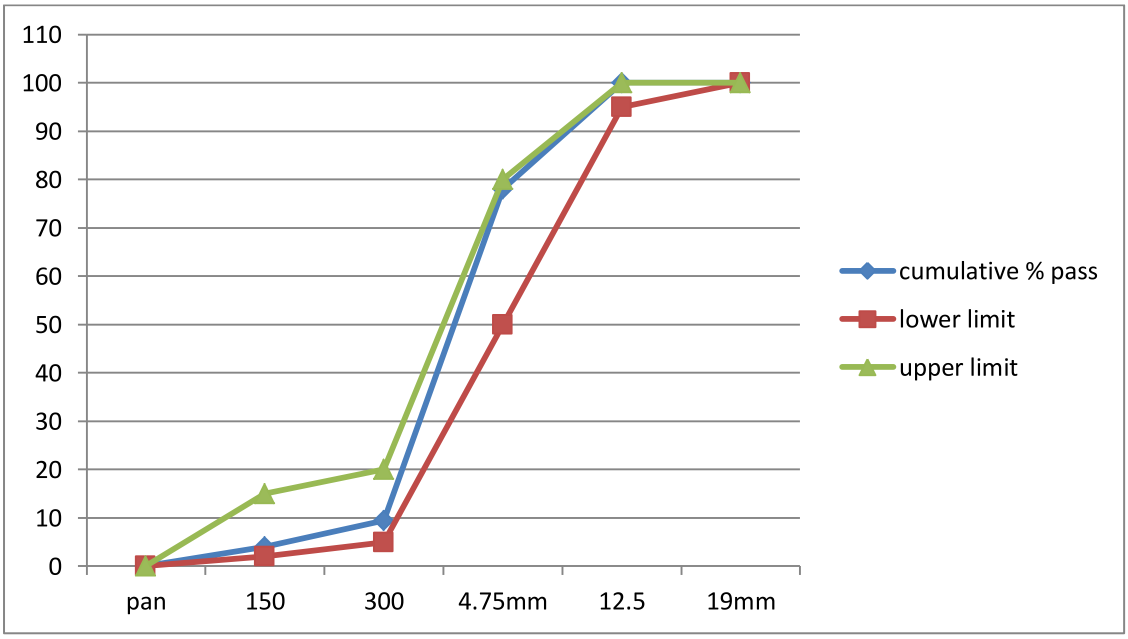

Figure 4.1 Scoria gradation curve

The Scoria was graded in accordance with ASTM C 331-94. This method is used to determine the particle size distribution of the coarse and fine aggregate down to 150µm. 2kg of the scoria sample being graded was collected from the bag where it was being stored. The scoria sample was then sieved through a standard set of sieve sizes. Once the scoria had been sieved, the mass of retained on each sieve could be measured. This allows for the cumulative mass of scoria passing each sieve size to be calculated after that plot grading curve with the cumulative percentage of scoria passing each sieve size against sieve size.

The grading requirements according to ASTM C331-94 including percentage passed of scoria sample that used for the experiment is shown above in figure 4.1 and the standard specification for lightweight aggregates for concrete masonry units which plotted were the result of scoria percentage passed on each sieve size used for the sieve analysis with the limit of the standard specification. The scoria size used in experimental test was combination of fine and coarse aggregates which had 12.5 to 0 mm. The detail sieve analysis of the scoria was found in appendix one on table 1A of this paper. Therefore, based on ASTM C331-94 standard specification the grading of the scoria sample result fulfills the standard requirement of concrete masonry units.

4.1.1.2 Clay lumps for Scoria

Scoria was one type of aggregate which categorized as lightweight. One of the properties made scoria to be lightweight is the maximum clay lumps content. The test method used was ASTM C142, and the complete test results are attached on appendix one of table 5A in data sheet for clay lumps. According to (ASTM C331-94), clay slumps content should not be greater than 2% for lightweight aggregate for concrete masonry units. As attached on appendix one on table 5A of this thesis both the fine and coarse aggregates are less than 2%, which means 1.83% in coarse and 1.46% in fine result respectively Therefore, the scoria fulfill the standards requirement lightweight aggregate used for concrete masonry unit production.

4.1.1.3 Unit weight of Scoria

Unit weight is another physical property of lightweight aggregates requirement for concrete masonry unit's production. Basically the scoria used in experimental test was combination of fine and coarse aggregates which had 64.35(1029.55) lb./ft^3(kg/m^3) max loose unit weight. According to the ASTM C331-94 max loose unit weight, lb. /ft^3 (kg/m^3) for combined fine and course aggregate was 65(1040). Based on the standard the result of scoria conducted during experiment test was fulfilling the requirement of the unit weight needed for concrete masonry unit's production.

4.1.1.4 Others physical properties determined

Some physical properties of light weight aggregate for concrete masonry units were discussed in ASTM C331-94, but the other physical properties of scoria conducted were such as moisture content, absorption and bulk specific gravity with the result of 0.84, 18.44 and

2.11% respectively. The light weight aggregate have averagely 5 to 20 % water absorption capacity. Therefore the experimental result water absorption capacity of scoria was 18.44% which had fulfill the requirement of the light weight aggregate.

4.1.2 Physical property tests on Ambo sandstone

4.1.1.1 Sieve analysis of Ambo sand stone

The test method used was (ASTM C331-94) and the detailed result obtained is attached on appendix **one.**

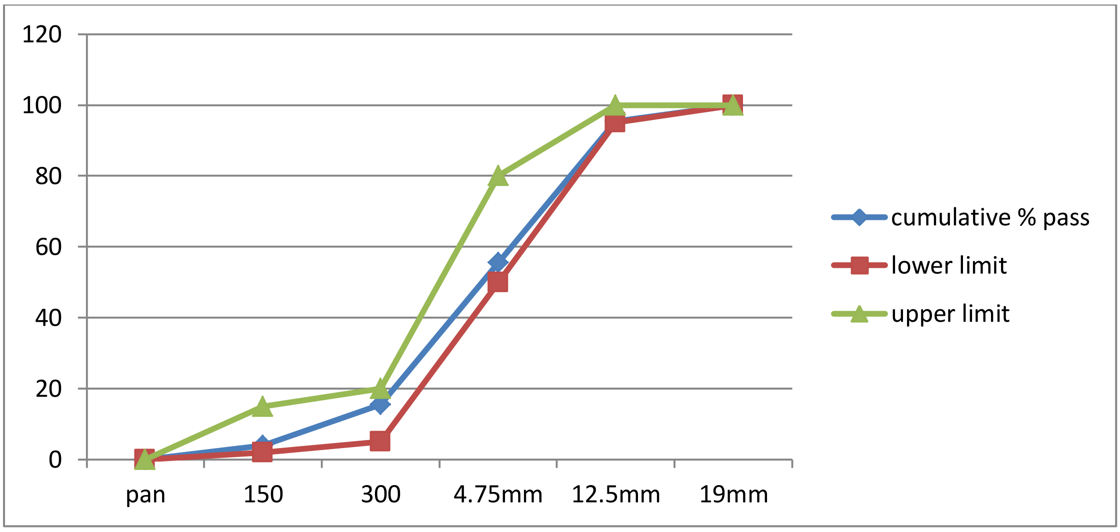

Figure 4.2 Ambo sandstone gradation curve

According to (ASTM C331-94) aggregates for Concrete Masonry Units used were the maximum size is 12.5 mm with combined aggregates (fine and coarse).To determine the grade of wastage of Ambo sandstone the experiment was done. The experiment conducted used to determine the particle size distribution of the coarse and fine aggregate down to 150µm. 2kg of the wastage of Ambo sandstone sample being graded was collected from the bag where it was being stored. The wastage of Ambo sandstone sample was then sieved through a standard set of sieve sizes. Once the scoria had been sieved, the mass of retained on each sieve could be measured. This allows for the cumulative mass of wastage of Ambo sandstone passing each sieve size to be calculated after that plot grading curve with the cumulative percentage of wastage of Ambo sandstone passing each sieve size against sieve size. The passing percentage requirements for combined aggregates (fine and coarse) were given in the figure 4.2 in terms of minimum percentage and maximum percentage pass for every sieve size plotted.

The ASTM C331-94 standard has its own upper and lower limit which guides the result of sieve analysis taken from the laboratory test which was meeting the standard requirement.

Therefore the conducted the experimental result of wastage of Ambo sandstone were in range of the standard specification of aggregates for concrete units, then the wastage of Ambo sandstone was the satisfied the requirement of the standard.

4.1.1.2 Clay lumps for Ambo sand stone

The other property Ambo sand stone as lightweight should fulfill is that the maximum clay lumps content. The test method used was ASTM C142, and the complete test results are attached on appendix one of table 10A in data sheet for clay lumps. According to (ASTM C331-94), clay slumps content should not be greater than 2% for lightweight aggregate for concrete masonry units. Both the fine and coarse aggregates clay lumps result were 1.83% and 1.41% respectively. Therefore the clay lumps specification standard were 2% which is greater than the result gone then the Ambo sand stone satisfy the needed result.

4.1.1.3 Unit weight of Ambo sandstone

Unit weight is the physical property of aggregates which used to determine the weight of the aggregates. According to ASTM C331-94 one of the physical properties required for production of the concrete masonry units was the unit weight of aggregates. The detail result of the unit weight of the wastage of Ambo sandstone was attached on the appendix one on table 7A of this paper. According to the ASTM C33 limits the unit weight of aggregate 1200-1760 kg/m^3 and the experimental result unit weight of wastage of Ambo sandstone was 1308.89 kg/m^3.Therefore based on the experimental result and the standard specification the wastage of Ambo sandstone fulfill the required the specification.

4.1.1.4 Others physical properties determined

The wastage of Ambo sandstone is one type of the aggregate which used for construction purpose and had its own physical properties such as moisture content, absorption and bulk specific gravity. The detail experimental result of those physical properties was attached on the appendix one. The results were 0.67, 7.51 and 2.64% for moisture content, absorption and bulk specific gravity respectively. The water absorption capacity of good light weight aggregates is up to 15%.Therefore the result of water absorption of wastage of Ambo sandstone was 7.51% which fulfill the requirement of the good light weight aggregates.

4.1.3 Physical property tests on 01Crushed aggregate

4.1.3.1 Sieve analysis of 01 Crushed aggregate

The test method used was (ASTM C 136) and the detailed result obtained is attached on appendix one of table 11A.

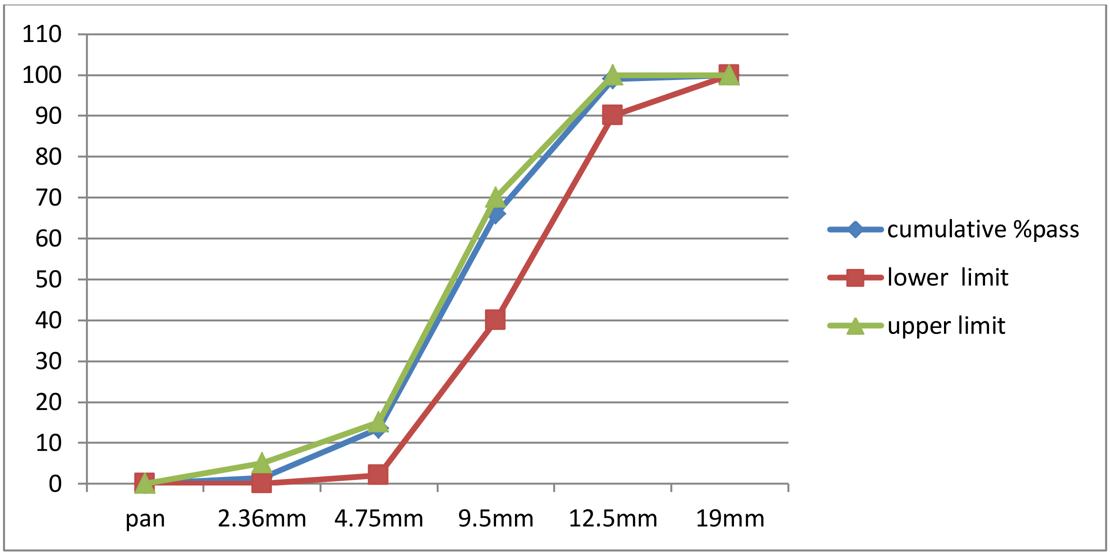

Figure 4.3 01 Crushed aggregate gradation curve

According to (ASTM C331-94) aggregates for Concrete Masonry Units used were the maximum size is 12.5 mm with combined aggregates. The experiment conducted used to determine the particle size distribution of the coarse and fine aggregate down to 2.36 mm. 2 kg of 01 crushed aggregate sample being graded was collected from the bag where it was being stored. The 01 crushed aggregates sample was then sieved through a standard set of sieve sizes. Once the 01 crushed aggregate had been sieved, the mass of retained on each sieve could be measured. This allows for the cumulative mass of 01 crushed aggregate passing each sieve size to be calculated after that plot grading curve with the cumulative percentage of 01 crushed aggregate passing each sieve size against sieve size. The passing percentage requirements for combined aggregates (fine and coarse) were given in the figure 4.3 in terms of minimum percentage and maximum percentage pass for every sieve size plotted. The ASTM C331-94 standard has its own upper and lower limit which guides the result of sieve analysis taken from the laboratory test which was meeting the standard requirement. The limit of the specification were described by color as follow green, blue and red for upper ,middle and lower respectively.

Therefore the conducted the experimental result of 01 crushed aggregates were in range of the standard specification of aggregates for concrete units, then the 01 crushed aggregates was the satisfied the requirement of the standard.

4.1.1.3 Unit weight of 01 crushed aggregate

Unit weight is one physical property of aggregate fulfill to be used as ingredient of concrete masonry units according to ASTM C331-94. The ASTM C33 limits the unit weight from 1200-1760 kg/m^3. The experimental result of 01 crushed aggregate was 1430.00kg/m3 which were found in the given standard. Therefore the experimental result of the 01 crushed aggregate unit weights was fulfilling the standard limitation of ASTM.

4.1.1.4 Others physical properties determined

The moisture content, absorption and bulk specific gravity were some physical properties of 01 crushed aggregate conducted during experimental. The experimental results were 0.5, 3.92 and 2.93% for moisture content, absorption and bulk specific gravity respectively. According to ASTM C33, the limitation for bulk specific gravity (SSD) is from 2.4 to 3.0, absorption from 0.2% to 4%, for coarse aggregates and the moisture contents should be within 0.5% to 2% .Therefore the experimental result of moisture content, absorption and bulk specific gravity of 01 crushed aggregate are with ASTM limitation**.**

4.2 physical properties of hollow concrete block

4.2.1 Workability

The workability was one of the most properties of concrete at fresh stage and depended on water cement ratio, size and shape of aggregate and aggregate cement ratio. The workability was determined by slump loss and hollow concrete block had true slump because the mix of the hollow concrete block was mixed at the dry mix. Mixes of stiff consistence have a zero slump,so that in the rather dry range no variation can be detected between mixes of different workability. Finer particles require more water to wet their larger specific surface,whilst the irregular shape and rougher texture of an angular aggregate demand more water than a rounded aggregate.The porosity or absorption of the aggregate was also important since some mixing water removed from that required for lubrication of the particles.Lightweight aggregate tends to lower the workability and workability is governed by the volumetric proportions particles of different sizes,so that when aggregates of varying specific gravity are used for constant w/c ratio the workability increases as the aggregate to cement ratio is reduced because the amount of water relative to the total surface of solids is increased.In this research the slump test result were similar at all replacement of wastage of Ambo sandstone with water cement ratio of 0.5. The selected water cement ratio for the HCB was 0.5, which is between (0.49- 0.55) that was recommended by GTZ Low Cost Housing Manual Volume I. According to the finding of the researcher the workability of the fresh concrete was constant through the percentage of replacement and the amount of water cement ratio decrease with incremental percentage of replacement of wastage of Ambo sandstone. This means as discussed in the physical properties of aggregate the scoria was more water absorptive and moisture content than the wastage of Ambo sandstone.

4.2.2 Density of the hollow concrete blocks

The density of each sample in figure 4.4 were calculated by dividing the weight by the volume of each hollow concrete blocks. Their weight is listed in appendix two with their corresponding compressive strengths. The figure 4.4 shows the variation of density of the hollow concrete block after 28th day.

The results showed that there was increase in hollow concrete block density with increase in wastage of Ambo sandstone proportion with values ranging from 886.04 kg/m3 for the control to 909.38, 915.31, 984.90, 1009.38 and 1198.54 kg/m^3 for 20, 40, 60, 80 and 100% respectively. The average density of the HCB with wastage of Ambo sandstone was 35.26% heavier than HCB without wastage of Ambo sandstone. This means the density of HCB was depend on the unit weight of aggregate used for the production. As discussed in the physical properties of aggregate the unit weight of wastage of Ambo sandstone was heavier than that of the scoria. As the result shown as the percentage replacement of wastage of Ambo sandstone increased the density of the HCB increased. However the HCB with wastage of Ambo sandstone was heavier than that of scoria the standard classify as light weight HCB.

According to ASTM C90-70 hollow concrete block have density less than 1682kg/m^3 were classified as light weight. Based on this standard the density of hollow concrete block produced had the value less the 1682 kg/m^3, therefore the HCB produced at all percentage replacement was classified as light weight. And also according to ES 596 (2001), the hollow concrete block which have density 900-1200 kg/m^3 were classified as A-C.

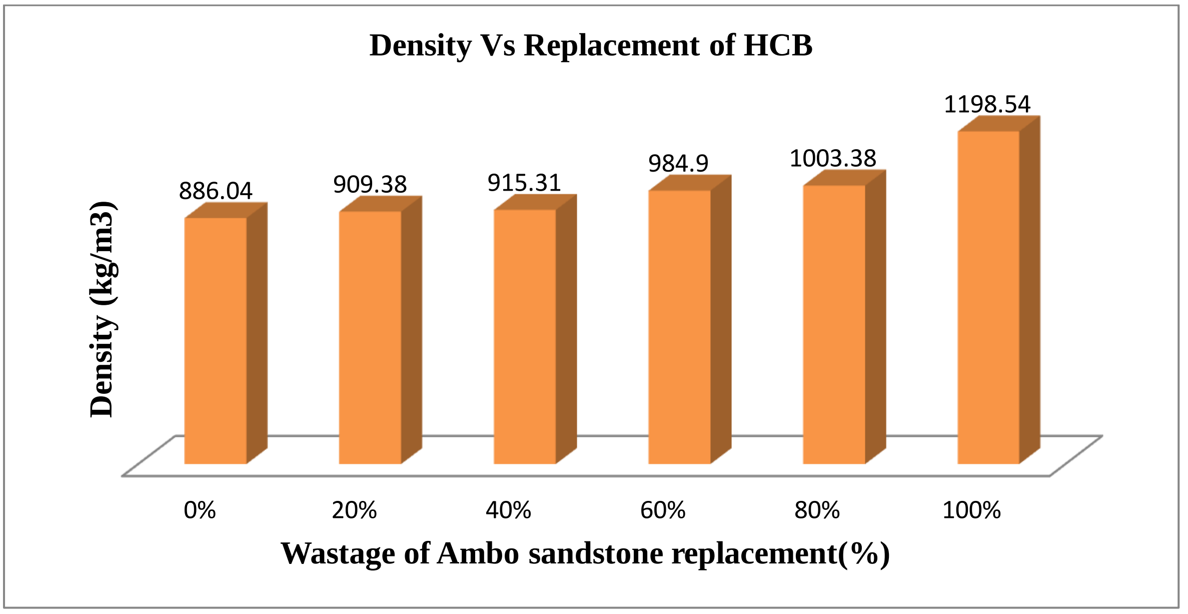

Figure 4.4 Density of HCB with wastage of Ambo sandstone replacement

4.2.3 Water Absorption

According to ASTM C140-70, the water absorption determined by completely immersed in water at room temperature for 24 hours and removed from the water and allowed to drain for one minute by placing them on a 10 mm wire mesh, visible surface water being removed with a dry cloth and immediately weighted and dried in oven dry for 24 hours at 100 °C to 115 °C.

The water absorption of hollow concrete blocks was calculated in appendix two of this research on table 18A and the summarized results of the test were listed as follows.

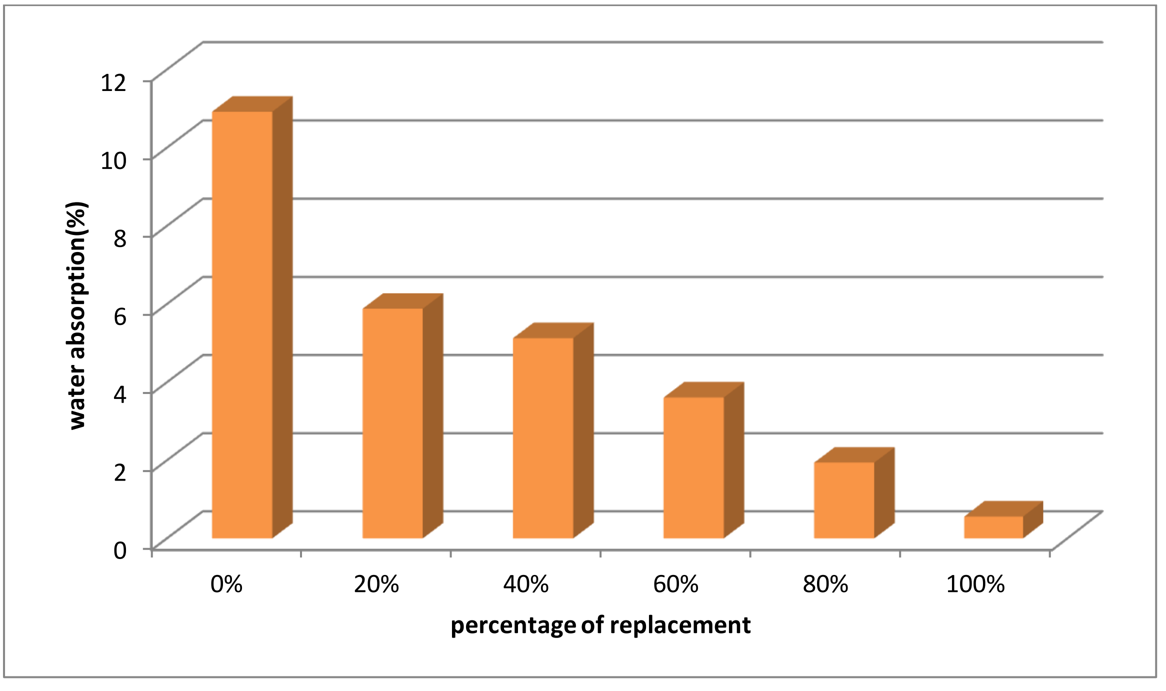

Figure 4.5 water absorption

As shown in table 4.5 the water absorption of hollow concrete block decreases as the amount of wastage of Ambo sandstone increase and with results of ranging from 10.95% for the control to 5.88, 5.13, 3.61, 1.94 and 0.56% for 20, 40, 60, 80 and 100% respectively. As the water absorption and moisture of the scoria and wastage of Ambo sandstone, the scoria was more water absorptive and moisture content than the wastage of Ambo sandstone. And also the HCB produced with scoria was more water absorptive than the HCB of wastage of Ambo sandstone. This indicates that the scoria was more porosity than the wastage of Ambo sandstone and HCB with wastage of Ambo sandstone was less water absorptive. Depending on this result the hollow concrete blocks produced by wastage of Ambo sandstone were more important than the scoria hollow concrete blocks.

According to the ASTM C90-70 the water absorption for the light weight HCB which have unit weight (density) less than 1360kg/m^{3}was absorptive water up to 20%. When the result of finding and the result of standard specification compared the result of density of HCB through the replacement is less 1360 kg/m^3 and water absorption also less than the required requirement. Based on the result the HCB produced with wastage of Ambo sandstone can be used without plastering because the water absorption was less than the other percentage of replacement.

4.3 Compressive strength of hollow concrete blocks at different percentage of replacement

To meet the objectives of this research, the compressive strength of each blocks produced was conducted according to ES 596:2001 after regularly cured by spraying water for 7 days. The compressive strength of each hollow concrete blocks is listed in the appendix two of this paper on table15A. The compressive strength of this HCB depends on percentage replacement of wastage of Ambo sandstone. To discus and analysis the compressive strength the researcher was analysis the compressive strength of HCB at different age and percentage of wastage of Ambo sandstone replacement.

4.2.1 Compressive strength of HCB at 7th day with different percentage replacement wastage of Ambo sandstone

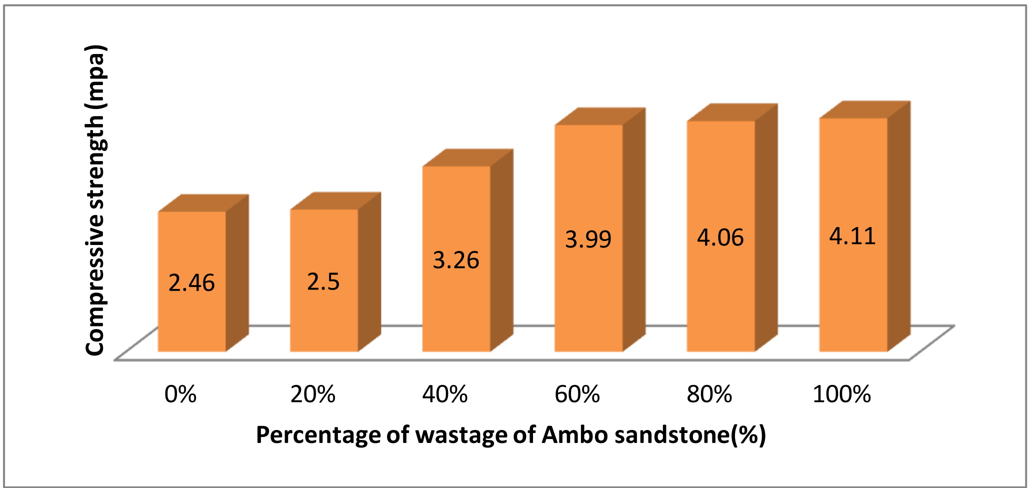

Figure 4.6 Compressive strength of HCB at 7th day with different percentage of replacement wastage of Ambo sandstone

Figure 4.6 shows the various 7th day compressive strengths. Generally the results showed increase in compressive strength with increase in the fraction of wastage of Ambo sandstone. The values of 2.46, 2.5, 3.26, 3.99, 4.06 and 4.11 Mpa were obtained for compressive strength with 0, 20, 40, 60, 80 and 100% wastage of Ambo sandstone as partial replacement. The compressive strength at 20% was slightly higher than that for control hollow concrete block. The replacements of wastage of Ambo sandstone fulfill the minimum compressive strength requirement of hollow concrete blocks. As shown from the figure 4.6 the maximum compressive strength was attended at 100% replacement and within 4.11Mpa compressive strength. This means that the nature of material used for the production of hollow concrete block made variation on the compressive strength.

The variation in compressive strength of HCB was the vcs $= \frac{\max - \min}{\min} * 100$. The variation of the compressive strength of the HCB at the 7th day was 1.63, 30.4, 22.39, 2.76 and 1.71% with the replacement percent change from 0 to 20%, 20 to 40%, 40 to 60%, and 60 to 80% and 80 to 100% respectively. According to (ES 596:2001), the mean minimum compressive strength of hollow concrete blocks was 2, 3.5, 4.5 and 5.5 Mpa. The maximum the compressive achieved at 100% of the replacement with 4.11 Mpa. The compressive strength of HCB with 60,80 and 100% replacement at 7th day was found between 3.5 and 4.5 Mpa compressive strength of (ES 596:2001). The compressive strength at 60,80 and 100% replacement was 14, 16 and 17.42 % stronger than 3.5 Mpa and 12.78, 10.83 and 9.48%

weaker than 4.5 Mpa compressive strength of the standard respectively. The compressive strength of HCB with 0, 20 and 40% replacement at 7th day was found between 2 and 3.5 Mpa. The compressive strength at 0, 20 and 40% replacement was 23, 25 and 63% stronger than 2 Mpa and 42.27, 40 and 7.36 % weaker than 3.5 Mpa compressive strength of the standard respectively.

4.2.2 Compressive strength of HCB at 14th day with different percentage replacement Ambo sand stone

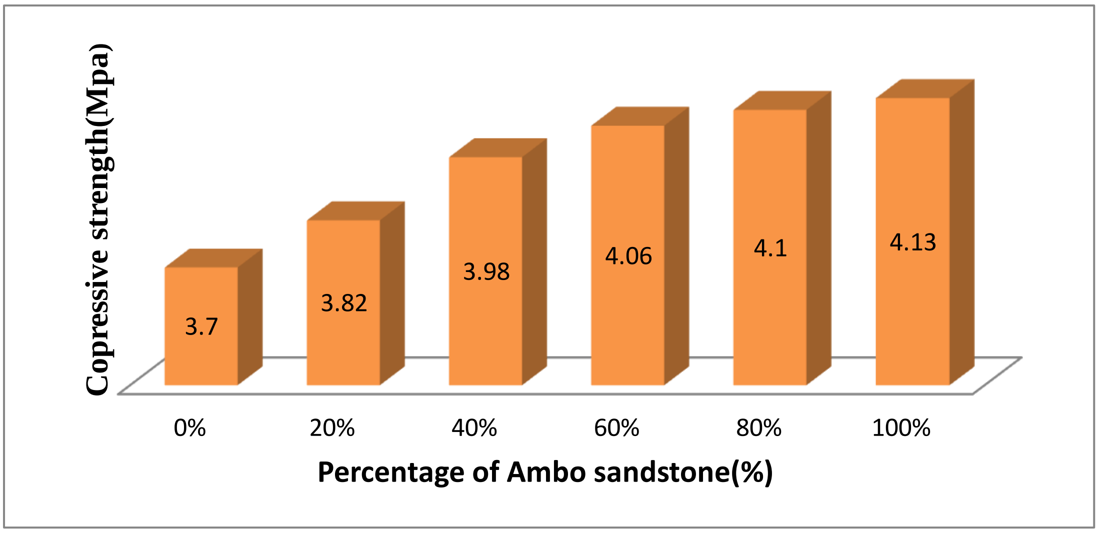

Figure 4.7 Compressive strength of HCB at 14th day with different percentage replacement of Ambo sandstone

Figure 4.7 shows the various 14th day compressive strengths. Generally the results showed increase in compressive strength with increase in the fraction of wastage of Ambo sandstone. The values of 2.46, 2.5, 3.26, 3.99, 4.06 and 4.11 Mpa were obtained for compressive strength with 0, 20, 40, 60, 80 and 100% wastage of Ambo sandstone as partial replacement. The compressive strength at 20% was slightly higher than that for control hollow concrete block. The replacements of wastage of Ambo sandstone fulfill the minimum compressive strength requirement of hollow concrete blocks. As shown from the figure 4.6 the maximum compressive strength was attended at 100% replacement and within 4.11Mpa compressive strength. This means that the nature of material used for the production of hollow concrete block made variation on the compressive strength.

The variation in compressive strength of HCB was the vcs $= \frac{\max - \min}{\min} * 100$.The variation of the of compressive strength of HCB at the age of 14th day was 3.24%, 4.19%, 2.01%, 0.99% and 0.73% with the replacement percent change of 0 to 20%, 20 to 40%, 40 to 60%, 60 to

80% and 80 to 100% respectively. According to (ES 596:2001), the mean minimum compressive strength of hollow concrete blocks was 2, 3.5, 4.5 and 5.5 Mpa. The maximum the compressive achieved at 100% of the replacement with 4.13 Mpa. The compressive strength of HCB with 0,20,40, 60,80 and 100% replacement at 14th day was found between 3.5 and 4.5 Mpa compressive strength according (ES 596:2001) standard. The compressive strength at 0, 20, 40, 60, 80 and 100% replacement was 5.71, 9.14, 13.71, 16, 17.14 and 18% stronger than 3.5 Mpa and 21.62, 17.80, 13.06, 10.83, 9.75 and 8.95% weaker than 4.5 Mpa compressive strength of the standard respectively.

4.2.3 Compressive strength of HCB at 28th day with different percentage replacement wastage Ambo sandstone

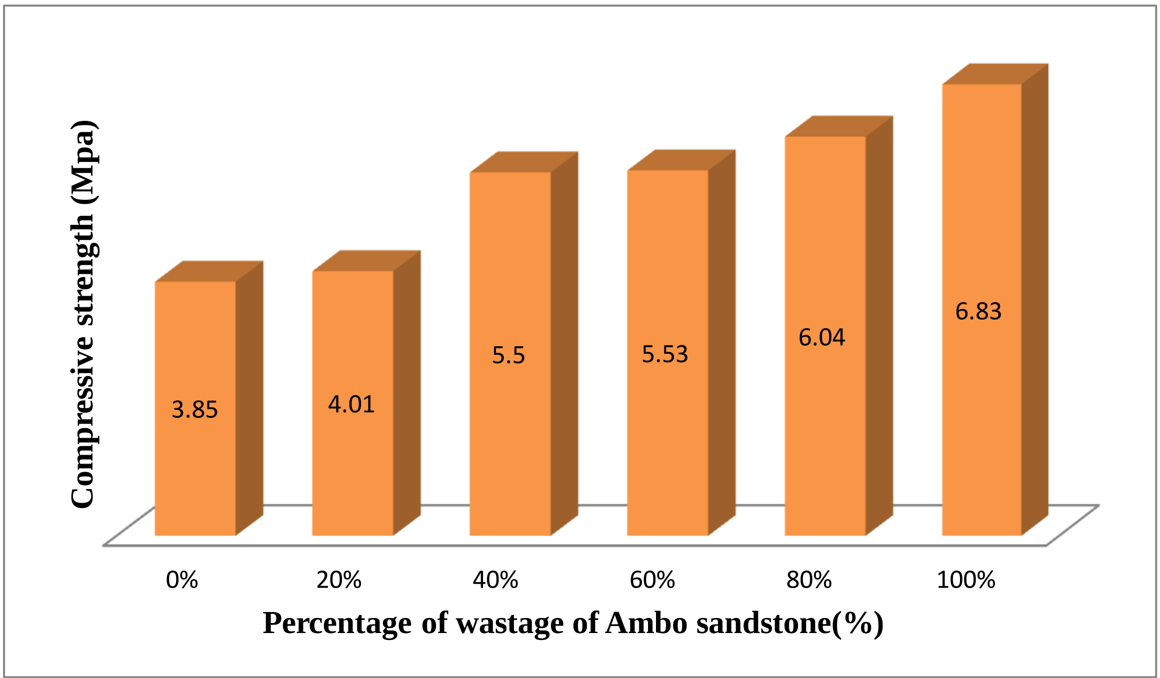

Figure 4.8 Compressive strength of HCB at 28th day with different percentage replacement wastage of Ambo sandstone

Figure 4.8 shows the various 28th day compressive strengths. Generally the results showed increase in compressive strength with increase in the fraction of wastage of Ambo sandstone. The values of 2.46, 2.5, 3.26, 3.99, 4.06 and 4.11 Mpa were obtained for compressive strength with 0, 20, 40, 60, 80 and 100% wastage of Ambo sandstone as partial replacement. The compressive strength at 20% was slightly higher than that for control hollow concrete block. The replacements of wastage of Ambo sandstone fulfill the minimum compressive strength requirement of hollow concrete blocks.

As shown from the figure 4.8 the maximum compressive strength was attended at 100% replacement and within 4.11Mpa compressive strength. This means that the nature of material used for the production of hollow concrete block made variation on the compressive strength.

Variation in compressive strength of the HCB was $vcs = \frac{max-min}{min} * 100$. the variation in compressive strength of the HCB at the age of 28th day was 4.16, 37.16, 0.55, 9.22 and 13.08% with the replacement percent change of 0 to 20%, 20 to 40%, 40 to 60%, 60 to 80% and 80 to 100% respectively. According to (ES 596:2001), the mean minimum compressive strength of hollow concrete blocks was 2, 3.5, 4.5 and 5.5 Mpa. The maximum the compressive achieved at 100% of the replacement with 6.83 Mpa. The compressive strength of HCB with 40, 60,80 and 100% replacement at 28th day was greater than 5.5 Mpa compressive strength of HCB according (ES 596:2001) standard. The compressive strength at 40, 60, 80 and 100% replacement was equal, 3, 9.81 and 24.18% stronger than 5.5 Mpa compressive strength of the standard respectively. The compressive strength of HCB with 0 and 20 replacements at 28th day was found between 3.5 and 4.5 Mpa. The compressive strength at 0 and 20% replacement was 10 and 14.57% stronger than 3.5 Mpa and 16.88 and 12.21 % weaker than 3.5 Mpa compressive strength of the standard respectively.

4.2.4 Compressive strength of HCB at different age

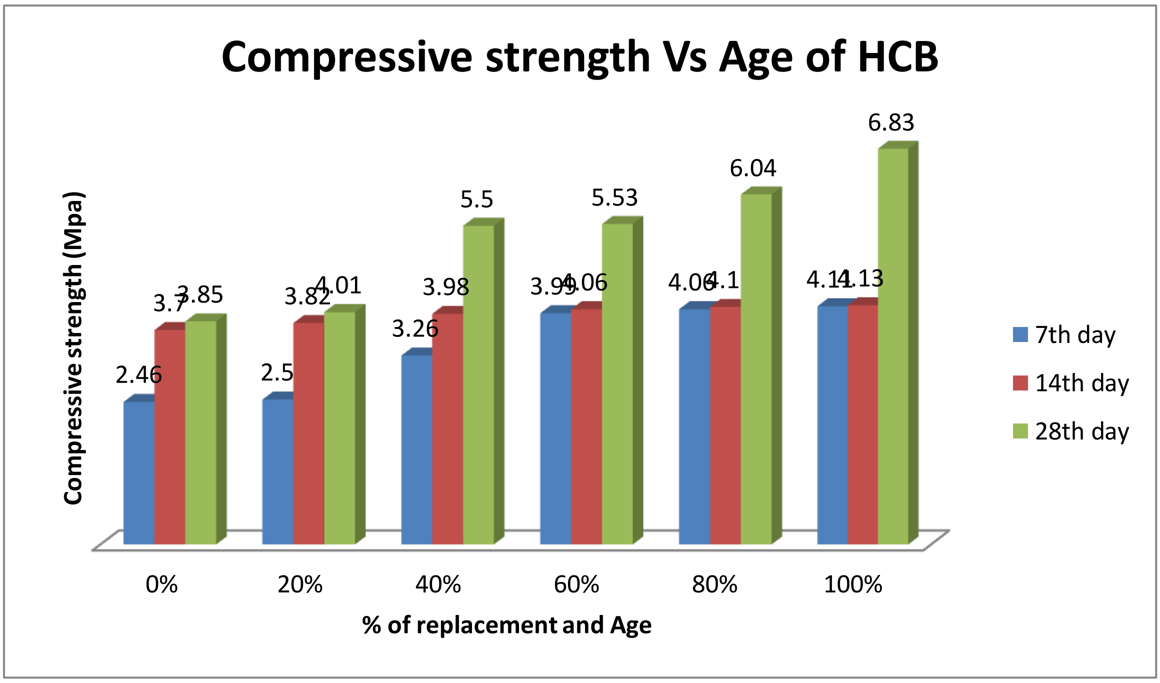

Figure 4.9 Compressive strength of HCB at different percentage of replacement and age

As shown in the figure 4.8 above as the age of hollow concrete blocks increased the compressive strength also increased. The percent of replacement and age are main parameter for incremental of compressive strength of hollow concrete block. On other hand the compressive strength is depending on the property of material and the duration it take. The detail result of the hollow concrete block was attached on appendix two of this paper and the summarized result was plotted shown on the figure 4.9.

As observed from the figure 4.9 the HCB with 0% replacement attained compressive strength 2.46, 3.7 and 3.85 Mpa; at 7^{th}, 14^{th} and 28^{th} day respectively and maximum mean compressive strength of HCB attained at 28^{th} day with 3.85 Mpa. At 7^{th} day the HCB attained 63.89% of the 28^{th} day compressive strength and at 14^{th} day the HCB attained 96.1% of the 28^{th} day compressive strength. The HCB with 20% replacement attained compressive strength of 2.5, 3.82 and 4.01Mpa at 7^{th}, 14^{th} and 28^{th} day respectively and the maximum mean compressive strength attained at 28^{th} day with 4.01 Mpa. At 7^{th} day the HCB attained 62.34% of the 28^{th} day compressive strength and at 14^{th} day the HCB attained 95.26% of the 28^{th} day compressive strength.

The HCB with 40% replacement attained compressive strength of 3.26, 3.98 and 5.5 Mpa at 7^{th}, 14^{th} and 28^{th} day respectively and the maximum mean compressive strength attained at 28^{th} day with 5.5Mpa. At 7^{th} day the HCB attained 59.27% of the 28^{th} day compressive strength and at 14^{th} day the HCB attained 72.36% of the 28^{th} day compressive strength. From the figure 4.9 the HCB with 60% replacement attained compressive strength of 3.99, 4.06 and 5.53 Mpa at 7^{th}, 14^{th} and 28^{th} day respectively and the maximum mean compressive strength attained at 28^{th} day with 5.53 Mpa. At 7^{th} day the HCB attained 72.15% of the 28^{th} day compressive strength and at 14^{th} day the HCB attained 73.41% of the 28^{th} day compressive strength.

With 80% replacement the HCB attained compressive strength of 4.06, 4.1 and 6.04 Mpa at 7^{th}, 14^{th} and 28^{th} day respectively and the maximum mean compressive strength attained at 28^{th} day with 6.04 Mpa. At 7^{th} day the HCB attained 67.21% of the 28^{th} day compressive strength and at 14^{th} day the HCB attained 67.88% of the 28^{th} day compressive strength. The HCB with 100% replacement attained compressive strength of 4.11, 4.13 and 6.83 Mpa at 7^{th}, 14^{th} and 28^{th} day respectively and the maximum mean compressive strength attained at 28^{th} day with 6.83 Mpa. At 7^{th} day the HCB attained 60.17% of the 28^{th} day compressive strength and at 14^{th} day the HCB attained 60.46% of the 28^{th} day compressive strength.

As presented in figure 4.7 above the compressive strength at 28th day was high when compared to the 7th and 14th day.

According to the Ethiopian standard ES 596(2001), the hollow concrete blocks depends on the result of 28th compressive strength. The maximum compressive strength recorded on the 28th day was 6.83 Mpa and the maximum compressive strength according to standard was 5.5 Mpa. When the two values compared to each other the compressive strength recorded at 28th day stronger by 24.18% than the maximum compressive strength of the standard. The minimum the compressive strength recorded at the 28th day was 3.85 Mpa and the minimum compressive strength according standard was 2 Mpa. When the two values compared to each other the compressive strength recorded at 28th day stronger by 92.5% than the standard.

4.4 Classifications of produced hollow concrete blocks according to Ethiopian Standard

According to Ethiopian Standards [ES 596:2001] Class A,B and C type of hollow concrete blocks are load-bearing whereas Class D hollow concretes are non-load bearings according to the mean minimum compressive requirements. According to ES hollow concrete block have 5.5, 4.5, 3.5 and 2.0 Mpa are the mean minimum compressive strength for Class A, B, C and D respectively and 5.0, 4.0, 3.0 and 1.8 Mpa individuals compressive strength respectively. The hollow concrete block class is classified depend on the 28th day compressive strength value. Based on ES the classes of the produced hollow concrete block was classified as follow in table 4.4

Table 4.1 Class of HCB produced according to Ethiopian Standard [ES 596:2001] at 28th day

HCB produced in replacement (%)	Minimum average compressive strength (Mpa)	Class
0	3.85	C
20	4.01	C
40	5.50	A
60	5.53	A
80	6.04	A
100	6.83	A

As shown in Table 4.1 the minimum average compressive strength at 28th day classify the produced HCB according to the [ES 596:2001] as A and C. According to this analysis the HCB produced with 0 and 20% of wastage of Ambo sandstone was classified as class C and the rest from 40 to 100% classified as class A.

4.5 Production cost analysis

After the production of hollow concrete blocks production it was sold to the construction company which used for the purpose of construction. This produced HCB had its own production cost which include the cost of 3m (material, machines and man power).

According to this study the production cost depends only on the cost of the two materials which is the scoria and wastage of Ambo sandstone, the cost include the transportation and price cost of the two materials.

The geological survey of Ethiopia the light weight aggregate were found in rift valley. Therefore the scoria is one of the light weights aggregate in which is special found around southern west shewa of oromia around waliso but wastage of Ambo sandstone was found west shewa around Ambo town. Depending on the location of the raw material the production cost analysis was done as follow and the detail of the cost analysis was appendix three on table 19A.

4.5.1 Unit cost of material per hollow concrete block

The production cost quantity of the raw material for one hollow concrete blocks was depending on the mix ratio which was 1:6 (1cement, 6 aggregate); the total of this batch produce 16 HCB. Then the quantity of ingredient found in one HCB was calculated as follow.

Table 4.2(a) Unit cost of material of hollow concrete block

Material	Price on local market	Quantity/HCB	Unit cost (birr)
Cement	2.2 birr/kg	3.125 kg	6.875
Scoria	160 birr/m^3	0.01 m^3	1.6
Ambo sand stone	50 birr/ m^3	0.01 m^3	0.5
01 crushed aggregate	500 birr/ m^3	0.005 m^3	2.5

The material cost for the cement and 01crushed aggregate was constant through at different replacement percent of wastage of Ambo sandstone. The local price of all material was known except the price of wastage of Ambo sandstone and the researcher calculate the price by using interview the society for what purpose they use and by how much price. The society use wastage of Ambo sandstone dries the mud place in their compound and they buy it by cart. The price of one cart was 50 birr and volume of the cart was 1 m^3 which mean 2 m * 1 m * 0.5 m size .Then the unit cost of material of wastage of Ambo sandstone and scoria were calculated as follows.

Table 4.2(b) Unit cost of wastage of Ambo sandstone and Scoria at different percentage of replacement

Percentage of replacement (%)	Quantity of material per hollow concrete block		Price of material per local market		Unit cost per quantity	
	Scoria(m^3)	Wastage of Ambo sandstone (m^3)	Scoria (birr/m^3)	Wastage of Ambo sandstone (birr/m^3)	Scoria (birr)	Wastage of Ambo sandstone (birr)
0	0.01	0	160	50	1.6	0
20	0.008	0.002	160	50	1.28	0.1
40	0.006	0.004	160	50	0.96	0.2
60	0.004	0.006	160	50	0.64	0.3
80	0.002	0.008	160	50	0.32	0.4
100	0	0.01	160	50	0	0.5

The quantity of the ingredient and unit cost of hollow concrete blocks were analyzed in different percentage of replacement. Finally to analyze the total unit cost of ingredient of one hollow concrete block were listed in the following table 4.2(c) as follows.

Table 4.2(c) the total unit cost of materials in one hollow concrete block

Replacement (%)	Unit cost of ingredient				Total unit cost of ingredient(birr)
	cement (birr)	scoria(birr)	Wastage of Ambo sandstone(birr)	01crushed aggregate(birr)	
0	6.875	1.6	0	2.5	10.975
20	6.875	1.28	0.1	2.5	10.755
40	6.875	0.96	0.2	2.5	10.535
60%	6.875	0.64	0.3	2.5	10.315
80%	6.875	0.32	0.4	2.5	10.095
100	6.875	0	0.5	2.5	9.875

4.5.2 Labor unit cost

The labor unit cost production is the payment paid for the lobar per production of one hollow concrete block. This cost was analyzed according to cost analysis of specification this means the labor unit cost was the number of labor * utility factor *hourly payment. The utility factor was number /hourly production. The labor unit cost of hollow concrete block was presented in table 4.8 below.

Table 4.3 labor unit cost of hollow concrete block

Labors	number	Utility factor (no/188) (per hr.)	Hourly payment (birr/hr.)	Unit cost /HCB (birr/HCB)
Operator	1	0.00532	18.75	0.09975
Daily labor	4	0.02128	10	0.8512
Total				0.9509

4.5.3 Unit cost of machinery

The unit cost of machinery was the payment paid for the machinery per day to produce hollow concrete block. Unit cost of machinery was the product of number * utility factor * hourly rental. The utility factor was the number /hourly production. The unit cost of machinery was calculated as follow in table below.

Table 4.4 machinery unit cost per hollow concrete block

Machinery type	number	Utility factor (no/188) (per hr.)	Hourly rental (birr/hr.)	Unit cost /HCB (birr/HCB)
Lay egg machine	1	0.00532	187.5	0.9975
Total				0.9975

Generally the unit cost of the production of hollow concrete block was the summation of the material cost, labor cost and machinery cost and the indirect cost. The indirect cost was including only the expenses used for fuel and oil of the machine which is approximately 5% of the direct cost. The unit cost of each was discussed in the table above and the summation of each them were summarized as follow.

Table 4.5 summation of production cost of one hollow concrete block at different replacement percent.

Replacement percent (%)	Material unit cost (Birr)	Labor unit cost (Birr)	Machinery unit cost (Birr)	HCB unit cost (Birr)	Indirect cost(Birr)	Total cost (Birr)
0	10.975	0.9509	0.9975	12.9229	0.6461	13.569
20	10.755	0.9509	0.9975	12.7034	0.6352	13.3276
40	10.535	0.9509	0.9975	12.4834	0.6242	13.1076
60	10.315	0.9509	0.9975	12.2634	0.6132	12.8766
80	10.095	0.9509	0.9975	12.0434	0.6022	12.6456
100	9.375	0.9509	0.9975	11.3234	0.5662	11.8896

As shown in table 4.5 as the percentage replacement increase the production cost of the hollow concrete block was decreased.

The table 4.5 shows the production cost of hollow concrete block with different replacement percentage of wastage of Ambo sandstone. The result shown us as amount of wastage of Ambo sandstone replaced increase the production cost of hollow concrete block decrease. The cost comparison between the 100% scoria and the 100% wastage of Ambo sand stone were result 1.6794 birr different when wastage of Ambo sandstone used instead of scoria per hollow concrete block.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The main objective of this study was to analyze the engineering properties of hollow concrete block produced by partial replacement of scoria with wastage of Ambo sandstone in Ambo town. During conducting this study result were concluded that:

The physical properties of the aggregates used for production of hollow concrete block were conducted with the ASTM C331 standard specification for concrete masonry units. The physical properties of the wastage of Ambo sandstone such as gradation, unit weight, moisture content, bulk specific gravity and absorption fulfill the requirement standard of the aggregate for the production of hollow concrete block.

The hollow concrete block produced with the replacement of wastage of Ambo sandstone was meet engineering properties such as workability, water absorption, density and compressive strength. The workability of the HCB was constant throughout the percentage of replacement because of the dry mix and the water absorption decrease with increasing of percentage of replacement. The density (unit weight) of the hollow concrete block proportional with the percentage of replacement and the result shows the wastage of Ambo sandstone was heavier than the scoria, but the ASTM C90-70 classify as light weight. The compressive strength increased as the percentage replacement of wastage of Ambo sandstone and age increased. The compressive strength results at all percentage replacement meet the minimum compressive strength of Ethiopia standard. The maximum compressive strength at 28^{th} day was 6.83 Mpa and this result meet at 100% replacement and the minimum compressive strength was 3.85 Mpa with 20% replacement. Based on the compressive strength 28^{th} the hollow concrete blocks were classified as class A and C with light weight.

The Cost of the hollow concrete block with wastage of Ambo sandstone was cheaper than the control HCB and reducing the cost by 1.6794 birr per hollow concrete block.

Finally the hollow concrete block produced with wastage of Ambo sandstone at all percentage of replacement were fulfilled the requirement of HCB with increase of compressive strength and density and; reduction of water absorption and production cost.

5.2 Recommendations

Based on the study conducted on the partial replacement of scoria with wastage of Ambo sandstone for production hollow concrete blocks, the following recommendation was made for the concerned bodies.

For Ambo town construction office

The office should create awareness to the company which produce hollow concrete block to use the wastage of Ambo sandstone instead of aggregate. The construction team unit should also encourage the micro and small enterprises to use wastage of Ambo sandstone for production of the hollow concrete block.

For the construction industry

If it produced properly with different percentage of replacement of wastage of Ambo sandstone it has high compressive strength, lower production cost and light weight when compared with other aggregate. Therefore it is recommend to the construction industry of Ambo town and around Ambo town if they use the wastage of Ambo sandstone instead of scoria to produce HCB because it reduce the cost and wastage of Ambo sandstone without any usage.

For research center

The governmental and non-government institution if they did further research on the title:

1. The effect wastage of Ambo sandstone as partial replacement of Aggregate in concrete

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Appendix one

Laboratory data sheet for physical properties

Place	**Jimma university**
Department	**Civil and Environmental engineering**
Laboratory	**Construction materials laboratory**

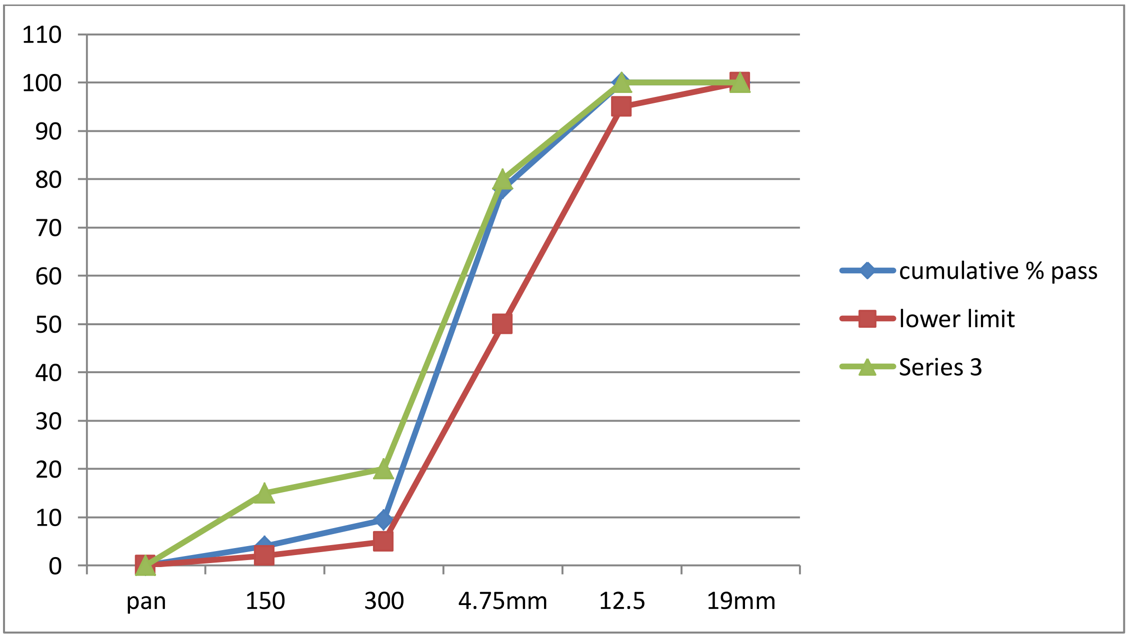
1. Sample description; Scoria

1 sieve analysis: test method ASTM C136

sieve size	Mass retained	%age mass retained	Cumulative retained (%)	Cumulative percent pass	ASTM standard
19mm	0kg	0	0	100	100
12.5mm	0kg	0	0	100	95-100
4.75mm	0.44kg	22	22	78	50-80
300m	1.37kg	68.5	90.5	9.5	5-20
150m	0.11kg	5.5	96	4	2-15
pan	0.08kg	4	100	0	0

Table 1A sieve analysis of scoria

Figure 1A Gradation curve of scoria



2.Unit Weight

Test method: **ASTM C129**

Samples	Sample1	Sample2	Sample3
Weight of container (A)	0.57kg	0.57kg	0.57kg
Weight of container + sample (B)	3.625kg	3.666kg	3.685kg
Weight of sample (B - A)=(D)	3.055kg	3.096kg	3.115kg
Volume of container (C)	0.003m^3	0.003m^3	0.003m^3
Unit weight =D/C	1,018.33kg/m^3	1,032kg/m^3	1,038.33kg/m^3
Mean unit weight	1,029.55kg/m^3		

Table 2A Unit weight of scoria

3.Mosture Content

Test method **:ASTM C566**

Samples	sample1	sample2	sample3
Weight of sample (A)	2kg	2kg	2kg
Oven dry weight (B)	1.985kg	1.980kg	1.985kg
Moisture (%)=(A-B/B)*100	0.760%	1.010%	0.760%
Mean moisture content	0.84%		

Table 3A Moisture content of scoria

4.Specific gravity and Absorption

Test method :ASTM C127

Samples		Sample1	Sample2	Sample3
Weight of oven dry sample in air	A	1.78kg	1.75kg	1.80kg
Weight of saturated surface dry sample in air	B	2.105 kg	2.104 kg	2.103 kg
Weight of wire in water	C	0.26 kg	0.26 kg	0.26 kg
Weight in water of (SSD) sample +wire basket	D	1.3 kg	1.4 kg	1.39 kg
Weight in water of SSD=D-C	E	1.04 kg	1.14 kg	1.13 kg
Bulk specific gravity (SSD)=B/(B-E)	BSG	1.98	2.18	2.16
Mean bulk specific gravity		2.11		
Absorption =((B-A)/A)*100	Abs	18.26%	20.23%	16.83%
Mean absorption		18.44%		

Table 4A Specific gravity and Absorption of scoria

5.Clay lumps
Test method: ASTM C142

Clay lumps for fine Scoria aggregate b/n 1.18-4.75mm				
Samples		sample1	sample2	sample3
Sample weight in gm.	W	100	100	100
Oven dry after wet sieve	R	98	97.5	99
% clay lumps and fabrics=((W-R)/W)*100	P	2	2.5	1
Mean clay lumps of fine aggregate in scoria %		1.83		

B/n 4.75mm-9.5mm

Samples		sample1	sample2	sample3
Sample weight in mg	W1	1000	1000	1000
Oven dry after wet sieve	R1	975	985	980
% clay lumps and fabrics=((W1-R1)/W1)*100	P1	2.5	1.5	2
Mean clay lumps of fine aggregate in scoria (%)		2.00		

Samples		sample1	sample2	sample3
Sample weight in mg	W2	2000	2000	2000
Oven dry after wet sieve	R2	1980	1985	1980
% clay lumps and fabrics=((W1-R1)/W1)*100	P2	1	0.75	1
Mean clay lumps of fine aggregate in scoria (%)		0.92		

Table 5A clay lamp of scoria

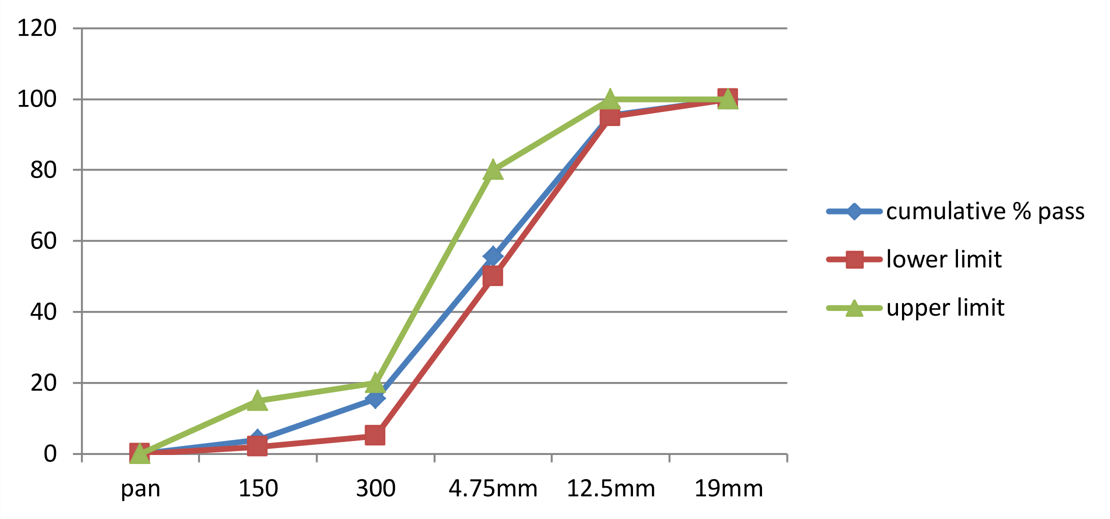
2. Sample description: Ambo sandstone

1. Sieve analysis

Test method: ASTM C331

sieve size	Mass retained	%age mass retained	Cumulative retained (%)	Cumulative percent pass	ASTM standard
19mm	0kg	0	0	100	100
12.5mm	0.09kg	4.5	4.5	95.5	95-100
4.75mm	1kg	50	54.5	45.5	50-80
300m	0.6kg	30	84.5	15.5	5-20
150m	0.23kg	11.5	96	4	2-5
pan	0.08kg	4	100	0	0

Figure 2A Gradation of wastage of Ambo sandstone



2.Unit Weight
Test method: **ASTM C129**

Samples	Sample1	Sample2	Sample3
Weight of container (A)	0.57kg	0.57kg	0.57kg
Weight of container + sample (B)	4.40kg	4.50kg	4.59kg
Weight of sample (B - A)=(D)	3.83kg	3.93kg	4.025kg
Volume of container (C)	0.003m^3	0.003m^3	0.003m^3
Unit weight =D/C	1,276.66 kg/m^3	1,310.00 kg/m^3	1,340 kg/m^3
Mean unit weight	1,308.89 kg/m^3		

Table 7A Unit weight of wastage of Ambo sandstone

3.Mosture Content
Test method: **ASTM C566**

Samples	sample1	sample2	sample3
Weight of sample (A)	2kg	2kg	2kg
Oven dry weight (B)	1.99kg	1.975kg	1.995kg
Moisture (%)=(A-B/B)*100	0.50%	1.26%	0.25%
Mean moisture content	0.67%		

Table 8A Moisture content of wastage of Ambo sandstone

4 Specific gravity and Absorption

		Sample1	Sample2	Sample3
Weight of oven dry sample in air	A	1.9 0kg	1.85 kg	1.90kg
Weight of saturated surface dry sample in air	B	2.05 kg	2.05 kg	2.06 kg
Weight of wire in water	C	0.26 kg	0.26 kg	0.26 kg
Weight in water of (SSD) sample +wire basket	D	1.5 kg	1.5 kg	1.6 kg
Weight in water of SSD=D-C	E	1.24 kg	1.24 kg	1.34 kg
Bulk specific gravity (SSD)=B/(B-E)	BSG	2.53	2.53	2.86
Mean bulk specific gravity		2.64		
Absorption =((B-A)/A)*100	Abs	7.89%	10.81%	7.89%
Mean absorption		7.51%		

Table 9A Specific gravity and Absorption of wastage of Ambo sandstone

5.Clay lumps

Test method:**ASTM C142**

Clay lumps for fine Ambo sand stone aggregate b/n 1.18-4.75mm

Samples		sampl e1	sample 2	sample 3
Sample weight in gm.	W	100	100	100
Oven dry after wet sieve	R	98.5	98	98
% clay lumps and fabrics=((W-R)/W)*100	P	1.5	2	2
Mean clay lumps of fine aggregate in Ambo sand stone (%)		1.83		

B/n 4.75mm-9.5mm

Samples		sampl e1	sample 2	sample 3
Sample weight in gm.	W1	1000	1000	1000
Oven dry after wet sieve	R1	985	985	980.5
% clay lumps and fabrics=((W1-R1)/W1)*100	P1	1.5	1.5	1.95
Mean clay lumps of fine aggregate in Ambo sand stone (%)		1.65		

Samples		sampl e1	sample 2	sample 3
Sample weight in gm.	W2	2000	2000	2000
Oven dry after wet sieve	R2	1975	1980	1975
% clay lumps and fabrics=((W1-R1)/W1)*100	P2	1.25	1	1.25
Mean clay lumps of fine aggregate in Ambo sand stone (%)		1.17		

Table 10A Clay lumps of wastage of Ambo sandstone

3.Sample description: 01 crushed aggregate

.1 sieve analysis

Test method :ASTM C331

sieve size	Mass Retained	%age mass retained	Cumulative retained (%)	Cumulative percent pass	ASTM standard
19mm	0	0	0	100	100
12.5mm	0.02	1	1	99	90-100
9.5mm	0.66	33	34	66	40-70
4.75mm	1.05	52.5	86.5	13.5	2-15
2.36mm	0.24	12	98.5	1.5	0-5
pan	0.03	1.5	100	0	0

Table 11A Sieve analysis of 01 crushed aggregate

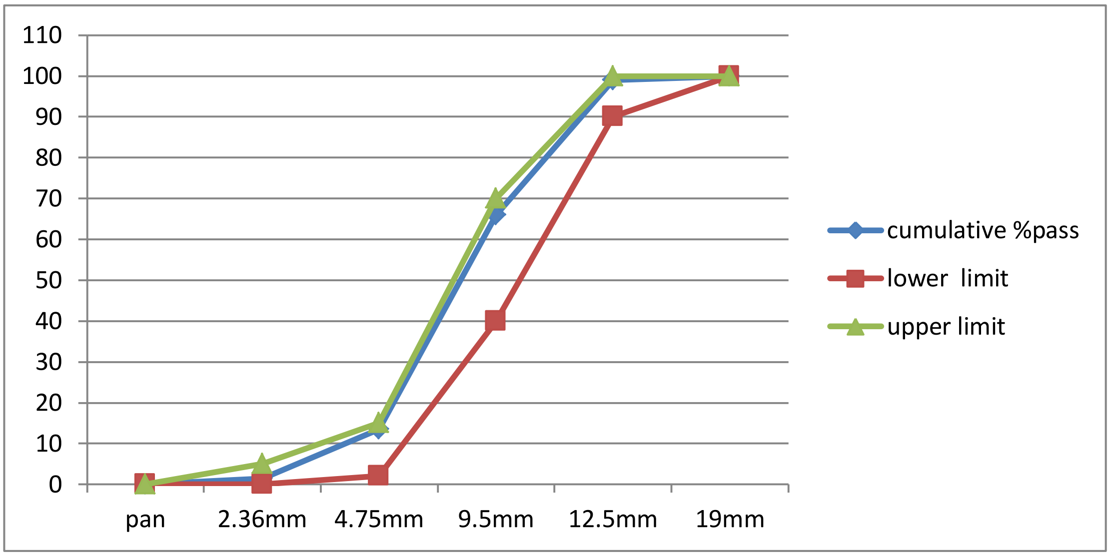


Figure 3A Gradation curve of 01 crushed aggregate

2.Unit Weight

Test method: ASTM C29

Samples	sample1	Sample2	Sample 3
Weight of container (A)	0.57 kg	0.57 kg	0.57 kg
Weight of container + Sample (B)	4.8 kg	4.85 kg	4.93 kg
Weight of sample (B - A)=(D)	4.23 kg	4.28 kg	4.36 kg
Volume of container (C)	$0.003m^3$	$0.003m^3$	$0.003\ m^3$
Unit weight =D/C	1,410.00 kg/m^3	1,426.67 kg/m^3	1,453.33 kg/m^3
Mean unit weight	1,430.00 kg/m^3		

Table 12A Unit weight of 01 crushed aggregate

3.3.Mosture Content

Test method: ASTM C 566

Samples	sample1	sample2	sample3
Weight of sample (A)	2kg	2kg	2kg
Oven dry weight (B)	1.995kg	1.99kg	1.985kg
Moisture (%)=(A-B/B)*100	0.25%	0.50%	0.76%
Mean moisture content	0.50%		

Table 13A Moisture content of 01 crushed aggregate

4.Specific gravity and absorption

Test method: ASTM C127

Samples		Sample1	Sample2	Sample3
Weight of oven dry sample in air	A	1.965kg	1.97kg	1.955kg
Weight of saturated surface dry sample in air	B	2.05kg	2.07kg	2.06kg
Weight of wire in water	C	0.26kg	0.26kg	0.26kg
Weight in water of (SSD) sample +wire basket	D	1.6kg	1.65kg	1.6kg
Weight in water of SSD=D-C	E	1.34kg	1.39kg	1.34kg
Bulk specific gravity (SSD)=B/(B-E)	BSG	2.89	3.04	2.86
Mean bulk specific gravity		2.93		
Absorption =((B-A)/A)*100	Abs	4.33%	4.08%	4.37%
Mean absorption		3.92%		

Table 14A Specific gravity and absorption of 01 crushed aggregate

Appendix Two
Laboratory data sheet for compressive strength

Place	**Jimma university**
Department	**Civil and Environmental engineering**
Laboratory	**Construction materials laboratory**

Table 15A Compressive strength of HCB at 7th with different %replacement

0% Ambo sandstone

Sample number	Caste date						**07/10/2009**
	Testing date						**13/10/2009**
	Dimension(cm)			Area(m2)	Weight(kg)	Failure Load(KN)	Compressive Strength (Mpa)
	L	W	H				
1	40	20	20	0.08	15.2	147.5	1.84
2				0.08	15.6	216	2.7
3				0.08	15.8	205	2.56
4				0.08	15	190	2.38
5				0.08	15.5	200	2.5
6				0.08	15.4	220	2.75
Mean Compressive Strength (Mpa)							**2.46**

20% Ambo sandstone

Sample number	**Caste date**						**07/10/2009**
	Testing date						**13/10/2009**
	Dimension(cm)			**Area (m2)**	**Weight(kg)**	**Failure Load(KN)**	**Compressive Strength(Mpa)**
	L	W	H				
1	40	20	20	0.08	16.19	372.5	4.66
2				0.08	15.37	166.6	2.08
3				0.08	15.48	350	4.38
4				0.08	15.8	280	3.5
5				0.08	16	215	2.69
6				0.08	15.54	190	2.38
Mean Compressive Strength (Mpa)							**2.50**

40% Ambo sandstone

Sample number	Caste date			07/10/2009			
	Testing date			13/10/2009			
	Dimension(cm)			Area(m2)	Weight(kg)	Failure Load(KN)	Compressive Strength(Mpa)
	L	W	H				
1	40	20	20	0.08	16.02	280.6	3.51
2				0.08	16.18	230.9	2.89
3				0.08	16	250.8	3.14
4				0.08	15.85	270.4	3.38
5				0.08	15.7	240.6	3.01
6				0.08	15.64	290.9	3.64
Mean Compressive Strength (Mpa)							**3.26**

60% Ambo sandstone

Sample number	Caste date			07/10/2009			
	Testing date			13/10/2009			
	Dimension(cm)			Area(m2)	Weight(kg)	Failure Load(KN)	Compressive Strength(Mpa)
	L	W	H				
1	40	20	20	0.08	16.66	323.1	4.04
2				0.08	16.2	318.7	3.98
3				0.08	16.5	320.5	4.01
4				0.08	16	312.5	3.91
5				0.08	15.95	315.6	3.95
6				0.08	15.85	325.6	4.07
Mean Compressive Strength (Mpa)							**3.99**

80% Ambo sandstone

Sample number	Caste date				07/10/2009		
	Testing date				13/10/2009		
	Dimension(cm)			Area(m2)	Weight(kg)	Failure Load(KN)	Compressive Strength(Mpa)
	L	W	H				
1	40	20	20	0.08	17.8	345.9	4.32
2				0.08	17.03	346	4.33
3				0.08	17.5	314.5	3.93
4				0.08	16.9	315.8	3.95
5				0.08	17.01	320.65	4.01
6				0.08	16.95	305.32	3.82
Mean Compressive Strength (Mpa)							**4.06**

100% Ambo sandstone

Sample number	Caste date				07/10/2009		
	Testing date				13/10/2009		
	Dimension(cm)			Area(m2)	Weight(kg)	Failure Load(KN)	Compressive Strength(Mpa)
	L	W	H				
1	40	20	20	0.08	19.6	351.8	4.40
2				0.08	19.06	350.36	4.38
3				0.08	18.6	315.12	3.94
4				0.08	19.7	305.23	3.82
5				0.08	19.2	325.36	4.07
6				0.08	18.9	326.0	4.08
Mean Compressive Strength (Mpa)							**4.11**

Table16A Compressive strength of HCB at 14th day with different % replacement

0% Ambo sandstone

Sample number	Caste date				07/10/2009		
	Testing date				20/10/2009		
	Dimension(cm)			Area(m2)	Weight(kg)	Failure Load(KN)	Compressive Strength(Mpa)
	L	W	H				
1	40	20	20	0.08	15.7	309.9	3.87
2				0.08	15.56	303.4	3.79
3				0.08	14.41	240.5	3.01
4				0.08	14.51	305	3.81
5				0.08	14.8	304.5	3.81
6				0.08	14.9	310.8	3.89
Mean Compressive Strength (Mpa)							**3.70**

20% Ambo sandstone

Sample number	Caste date				07/10/2009		
	Testing date				20/10/2009		
	Dimension(cm)			Area(m2)	Weight(kg)	Failure Load(KN)	Compressive Strength(Mpa)
	L	W	H				
1	40	20	20	0.08	14.56	228.8	2.86
2				0.08	15.11	310.9	3.89
3				0.08	14.6	341.3	4.27
4				0.08	14.75	330.5	4.13
5				0.08	14.95	305.2	3.82
6				0.08	14.25	316.8	3.96
Mean Compressive Strength (Mpa)							**3.82**

40% Ambo sandstone

Sample number	Caste date						07/10/2009
	Testing date						20/10/2009
	Dimension(cm)			Area(m2)	Weight(kg)	Failure Load(KN)	Compressive Strength(Mpa)
	L	W	H				
1	40	20	20	0.08	14	281.8	3.52
2				0.08	15.11	289.7	3.62
3				0.08	14.92	350.6	4.38
4				0.08	14.53	335.6	4.20
5				0.08	14.85	325.6	4.07
6				0.08	14.78	326.5	4.08
Mean Compressive Strength (Mpa)							**3.98**

60% Ambo sandstone

Sample number	Caste date						07/10/2009
	Testing date						20/10/2009
	Dimension(cm)			Area(m2)	Weight(kg)	Failure Load(KN)	Compressive Strength(Mpa)
	L	W	H				
1	40	20	20	0.08	14.23	286.7	3.58
2				0.08	15.75	329.4	4.12
3				0.08	15.5	301.1	3.76
4				0.08	16.28	376.9	4.71
5				0.08	15.6	315.56	3.94
6				0.08	14.53	340.23	4.25
Mean Compressive Strength (Mpa)							**4.06**

80% Ambo sandstone

Sample number	Caste date				07/10/2009		
	Testing date				20/10/2009		
	Dimension(cm)			Area(m2)	Weight(kg)	Failure Load(KN)	Compressive Strength(Mpa)
	L	W	H				
1	40	20	20	0.08	15.18	204.4	2.56
2				0.08	16.55	537.5	6.72
3				0.08	16.6	348.6	4.36
4				0.08	15.6	315.6	3.95
5				0.08	15.75	290.5	3.63
6				0.08	16	270.9	3.39
Mean Compressive Strength (Mpa)							**4.10**

100% Ambo sandstone

Sample number	Caste date				07/10/2009		
	Testing date				20/10/2009		
	Dimension(cm)			Area(m2)	Weight(kg)	Failure Load(KN)	Compressive Strength(Mpa)
	L	W	H				
1	40	20	20	0.08	19.3	342.4	4.28
2				0.08	19	330.3	4.13
3				0.08	18.9	321.5	4.02
4				0.08	19.2	311.6	3.90
5				0.08	18.8	329.2	4.12
6				0.08	19.5	346.9	4.34
Mean Compressive Strength (Mpa)							**4.13**

Table 17A Compressive strength of HCB at 28th day with different % replacement

0% Ambo sandstone

Sample number	**Caste date**				**07/10/2009**		
	Testing date				**05/11/2009**		
	Dimension(cm)			**Area(m2)**	**Weight(kg)**	**Failure Load(KN)**	**Compressive Strength(Mpa)**
	L	W	H				
1	40	20	20	0.08	14.2	322.9	4.04
2				0.08	14.35	275.9	3.45
3				0.08	15.34	362.4	4.53
4				0.08	13.79	275.4	3.44
5				0.08	15.32	322.3	4.03
6				0.08	14.3	290.6	3.63
Mean Compressive Strength (Mpa)							**3.85**

20% Ambo sandstone

Sample number	**Caste date**				**07/10/2009**		
	Testing date				**05/11/2009**		
	Dimension(cm)			**Area(m2)**	**Weight(kg)**	**Failure Load(KN)**	**Compressive Strength(Mpa)**
	L	W	H				
1	40	20	20	0.08	14.45	341.9	4.27
2				0.08	14.35	334.5	4.18
3				0.08	14.16	233.8	2.92
4				0.08	14.15	350.2	4.38
5				0.08	14	340	4.25
6				0.08	13.95	326.6	4.08
Mean Compressive Strength (Mpa)							**4.01**

40% Ambo sandstone

Sample number	Caste date				07/10/2009		
	Testing date				05/11/2009		
	Dimension(cm)			Area(m2)	Weight(kg)	Failure Load(KN)	Compressive Strength(Mpa)
	L	W	H				
1	40	20	20	0.08	14.8	645.7	8.07
2				0.08	14.82	648.9	8.11
3				0.08	14.7	335.4	4.19
4				0.08	14.6	342.8	4.29
5				0.08	14.5	336.5	4.21
6				0.08	14.45	329.8	4.12
Mean Compressive Strength (Mpa)							**5.50**

60% Ambo sandstone

Sample number	Caste date				07/10/2009		
	Testing date				05/11/2009		
	Dimension(cm)			Area(m2)	Weight(kg)	Failure Load(KN)	Compressive Strength(Mpa)
	L	W	H				
1	40	20	20	0.08	16.2	429.1	5.36
2				0.08	15.9	386.6	4.83
3				0.08	15.8	535.8	6.70
4				0.08	16.2	415.5	5.19
5				0.08	16.3	415.35	5.19
6				0.08	16.5	472.36	5.90
Mean Compressive Strength (Mpa)							**5.53**

80% Ambo sandstone

Sample number	**Caste date**						**07/10/2009**
	Testing date						**05/11/2009**
	Dimension(cm)			**Area(m2)**	**Weight(kg)**	**Failure Load(KN)**	**Compressive Strength(Mpa)**
	L	W	H				
1	40	20	20	0.08	15.57	625.8	7.82
2				0.08	16.81	408.4	5.11
3				0.08	15.75	396.2	4.95
4				0.08	15.54	622.2	7.78
5				0.08	15.25	420.5	5.26
6				0.08	15.63	424.9	5.31
Mean Compressive Strength (Mpa)							**6.04**

100% Ambo sandstone

Sample number	**Caste date**						**07/10/2009**
	Testing date						**05/11/2009**
	Dimension(cm)			**Area(m2)**	**Weight(kg)**	**Failure Load(KN)**	**Compressive Strength(Mpa)**
	L	W	H				
1	40	20	20	0.08	18.9	526.1	6.58
2				0.08	19.66	552.1	6.90
3				0.08	19.3	659.2	8.24
4				0.08	19	515.25	6.44
5				0.08	18.85	510.5	6.38
6				0.08	19.35	516.32	6.45
Mean Compressive Strength (Mpa)							**6.83**

Table 18A Water absorption of HCB

Water absorption of hollow concrete blocks

SAMPLE	0%	20%	40%	60%	80%	100%
Weight of oven dry sample in air (kg)	14.2	14.45	14.82	15.25	15.45	18
Weight of saturated surface dry sample in air(kg)	15.75	15.3	15.58	15.8	15.75	18.1
Absorption = ((B-A)/A)*100(%)	10.92	5.88	5.13	3.61	1.94	0.56

APPENDEX THREE

Production cost analysis

Table 19A Production cost analysis

	Item :HCB with 0% of wastage of Ambo sandstone												Labour hourly output :188psc/hr	
													Equipment hourly output:188pcs/hr	
	Unit :pcs												Resultant : 188	pcs/hr
		Material cost					Labor cost					Equipment cost		
Material type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed hourly cost	Total	Equipment type	Qty	UF	Operator hourly cost	Total
Cement	kg	3.125	2.2	6.875	Operater	1	0.00532	18.75	0.09975	Egg laying ma	1	0.00532	187.5	0.9975
soria	m3	0.01	160	1.6	D/L	4	0.02128	10	0.8512					
Ambo sand stone	m3	0	50	0										
01 crushed aggregate	m3	0.005	500	2.5										
Total				10.98	Total				0.95095	Total				0.9975
A = Material Unit Cost	10.975				B = Manpower Unit Cost	0.95095				C = Equipment Unit Cost :	0.9975			
							Direct Cost of Work Item =A+B+C =			12.92				
							Over head cost : 5% of DC =			0.65				
							Total Unit Cost =DC+OHC			13.57				

	Item :HCB with 20% of wastage of Ambo sandstone												Labour hourly output :188psc/hr	
													Equipment hourly output:188pcs/hr	
	Unit :pcs												Resultant : 188	pcs/hr
		Material cost					Labor cost					Equipment cost		
Material type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed hourly cost	Total	Equipment type	Qty	UF	Operator hourly cost	Total
Cement	kg	3.125	2.2	6.875	Operater	1	0.00532	18.75	0.09975	Egg laying ma	1	0.00532	187.5	0.9975
soria	m3	0.008	160	1.28	D/L	4	0.02128	10	0.8512					
Ambo sand stone	m3	0.002	50	0.1										
01 crushed aggregate	m3	0.005	500	2.5										
Total				10.76	Total				0.95095	Total				0.9975
A = Material Unit Cost	10.755				B = Manpower Unit Cost	0.95095				C = Equipment Unit Cost :	0.9975			
							Direct Cost of Work Item =A+B+C =			12.70				
							Over head cost : 5% of DC =			0.64				
							Total Unit Cost =DC+OHC			13.34				

	Item :HCB with 40% of wastage of Ambo sandstone												Labour hourly output :188psc/hr	
													Equipment hourly output:188pcs/hr	
	Unit :pcs												Resultant : 188	pcs/hr
		Material cost					Labor cost					Equipment cost		
Material type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed hourly cost	Total	Equipment type	Qty	UF	Operator hourly cost	Total
Cement	kg	3.125	2.2	6.875	Operater	1	0.00532	18.75	0.09975	Egg laying ma	1	0.00532	187.5	0.9975
soria	m3	0.006	160	0.96	D/L	4	0.02128	10	0.8512					
Ambo sand stone	m3	0.004	50	0.2										
01 crushed aggregate	m3	0.005	500	2.5										
Total				10.54	Total				0.95095	Total				0.9975
A = Material Unit Cost	10.535				B = Manpower Unit Cost	0.95095				C = Equipment Unit Cost :	0.9975			
							Direct Cost of Work Item =A+B+C =			12.48				
							Over head cost : 5% of DC =			0.62				
							Total Unit Cost =DC+OHC			13.11				

Item :HCB with 60% of wastage of Ambo sandstone

Labour hourly output :188psc/hr
Equipment hourly output:188pcs/hr
Resultant : 188 pcs/hr

Unit :pcs

		Material cost					Labor cost					Equipment cost		
Material type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed hourly cost	Total	Equipment type	Qty	UF	Operator hourly cost	Total
Cement	kg	3.125	2.2	6.875	Operater	1	0.00532	18.75	0.09975	Egg laying ma	1	0.00532	187.5	0.9975
soria	m3	0.004	160	0.64	D/L	4	0.02128	10	0.8512					
Ambo sand stone	m3	0.006	50	0.3										
01 crushed aggregate	m3	0.005	500	2.5										
Total				10.32	Total				0.95095	Total				0.9975

A = Material Unit Cost 10.315 B = Manpower Unit Cost 0.95095 C = Equipment Unit Cost : 0.9975

Direct Cost of Work Item =A+B+C =	12.26
Over head cost : 5% of DC =	0.61
Total Unit Cost =DC+OHC	12.88

Item :HCB with 80% of wastage of Ambo sandstone

Labour hourly output :188psc/hr
Equipment hourly output:188pcs/hr
Resultant : 188 pcs/hr

Unit :pcs

		Material cost					Labor cost					Equipment cost		
Material type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed hourly cost	Total	Equipment type	Qty	UF	Operator hourly cost	Total
Cement	kg	3.125	2.2	6.875	Operater	1	0.00532	18.75	0.09975	Egg laying ma	1	0.00532	187.5	0.9975
soria	m3	0.002	160	0.32	D/L	4	0.02128	10	0.8512					
Ambo sand stone	m3	0.008	50	0.4					0					
01 crushed aggregate	m3	0.005	500	2.5					0					
									0					
Total				10.10	Total				0.95095	Total				0.9975

A = Material Unit Cost 10.095 B = Manpower Unit Cost 0.95 C = Equipment Unit Cost : 0.9975

Direct Cost of Work Item =A+B+C =	12.04
Over head cost : 5% of DC =	0.60
Total Unit Cost =DC+OHC	12.65

tem :HCB with 100% of wastage of Ambo sandstone

Labour hourly output :188psc/hr
Equipment hourly output:188pcs/hr
Resultant : 188 pcs/hr

Unit :pcs

		Material cost					Labor cost					Equipment cost		
Material type	Unit	Qty	Rate	Cost/Unit	Title	Qty	UF	Indexed hourly cost	Total	Equipment type	Qty	UF	Operator hourly cost	Total
Cement	kg	3.125	2.2	6.875	Operater	1	0.00532	18.75	0.09975	Egg laying ma	1	0.00532	187.5	0.9975
soria	m3	0	160	0	D/L	4	0.02128	10	0.8512					
Ambo sand stone	m3	0.01	50	0.5										
01 crushed aggregate	m3	0.005	500	2.5										
Total				9.88	Total				0.95095	Total				0.9975

A = Material Unit Cost 9.875 B = Manpower Unit Cost 0.95095 C = Equipment Unit Cost : 0.9975

Direct Cost of Work Item =A+B+C =	11.82
Over head cost : 5% of DC =	0.59
Total Unit Cost =DC+OHC	12.41

APPENDIX FOUR
SAMPLE PHOTO GALLERY TAKEN DURING THE RESEARCH